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COIMBRA

Beatriz Oliveira Reis da Rocha Lagos

Workout Music Station

An Interactive System for People with ASD

Dissertation in the context of the Master in Electrical and Computer Engineering, advised by Professor Paulo Jorge Carvalho Menezes, and presented to the Department of Electrical and Computer Engineering of the Faculty of Sciences and Technology of the University of Coimbra

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Abstract

Autism Spectrum Disorder (ASD), commonly referred to as autism, is a prevalent and highly hereditary neurodevelopmental disorder characterized by a diverse range of cognitive traits. It is characterized by challenges in social interaction, communication, motor and visual coordination, memory and focus, and the presence of restricted or repetitive behaviors, making it a lifelong condition that significantly impacts an individual's daily functioning, relationships, and overall well-being. Recognizing the need for tailored solutions to address these unique obstacles, this project was initiated to develop and assess interactive educational applications and games explicitly designed to cater to the needs of individuals with autism and related characteristics. Leveraging Python, Blender, and Motion Capture technologies, the project integrates a diverse array of tools for the comprehensive development of the interactive system. Using Python to develop the interactive system, enabling the individual to use the application and play the games at a distance, in the form of hand and other body parts recognition, Blender to develop the avatar from scratch and Motion Capture to create its movements. The evaluation phase encompasses both participants with and without autism characteristics, yielding valuable insights into the efficacy of the application. The results underscore the app's potential to deliver positive benefits for individuals with autism and lay the groundwork for prospective improvements and advancements.

Keywords: Autism Spectrum Disorder, Interactive Games, Python, Blender, Motion Capture, Avatar.

Resumo

O Transtorno do Espectro do Autismo (TEA), normalmente referido como autismo, é um transtorno do neurodesenvolvimento prevalente e altamente hereditário, caracterizado por uma ampla gama de características cognitivas. É caracterizado por desafios de interação social, comunicação, coordenação motora e visual, memória e foco, e a presença de comportamentos restritos ou repetitivos, tornando-se uma condição permanente que impacta significativamente o funcionamento diário, os relacionamentos e o bem-estar geral de um indivíduo. Reconhecendo a necessidade de soluções personalizadas para ultrapassar estes obstáculos, este projecto foi criado para desenvolver e avaliar uma aplicação educativa que contém jogos interactivos, explicitamente concebidos para satisfazer as necessidades de indivíduos com autismo e características relacionadas. Usufruindo das tecnologias Python, Blender e Motion Capture, o projeto integra uma gama diversificada de ferramentas para o desenvolvimento abrangente do sistema interativo. Utilizando Python para desenvolver o sistema interativo, possibilitando ao indivíduo utilizar a aplicação e jogar os jogos à distância, na forma de reconhecimento de mãos e outras partes do corpo, Blender para desenvolver o avatar do zero e Motion Capture para criar os seus movimentos. A fase de avaliação abrange participantes com e sem características de autismo, produzindo informações valiosas sobre a eficácia da aplicação. Os resultados ressaltam o potencial do aplicativo para proporcionar benefícios positivos para indivíduos com autismo e estabelecer as bases para possíveis melhorias e avanços.

Palavras-chave: Transtorno do Espectro do Autismo, Jogos Interactivos, Python, Blender, Motion Capture, Avatar.

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Chapter 1

Introduction

Autism spectrum disorder (ASD), also known as autism, is a common, highly heritable and heterogeneous neurodevelopmental disorder that has underlying cognitive features and commonly co-occurs with other conditions [54]. It is characterized by challenges in social interaction, communication, motor and visual coordination, memory and focus, and the presence of restricted or repetitive behaviors, making it a lifelong condition that significantly impacts an individual's daily functioning, relationships, and overall well-being.

Over the years, there has been increased awareness and understanding of autism, leading to improved diagnosis and also the exponential grow of the number of people diagnosed with that condition. However, as Walter Zahorodny, an associate professor of pediatrics at Rutgers New Jersey Medical School, said in a press release: "Changes in awareness, shifts in how children are identified or diagnosed, factors related to awareness are relevant, but only take you so far in accounting for an increase of this magnitude" [55]. Using the United States as reference, we can see that autism prevalence started raising in the 2000's and hasn't stopped until more recent years, as it is represented in the graph of the Figure 1.1.

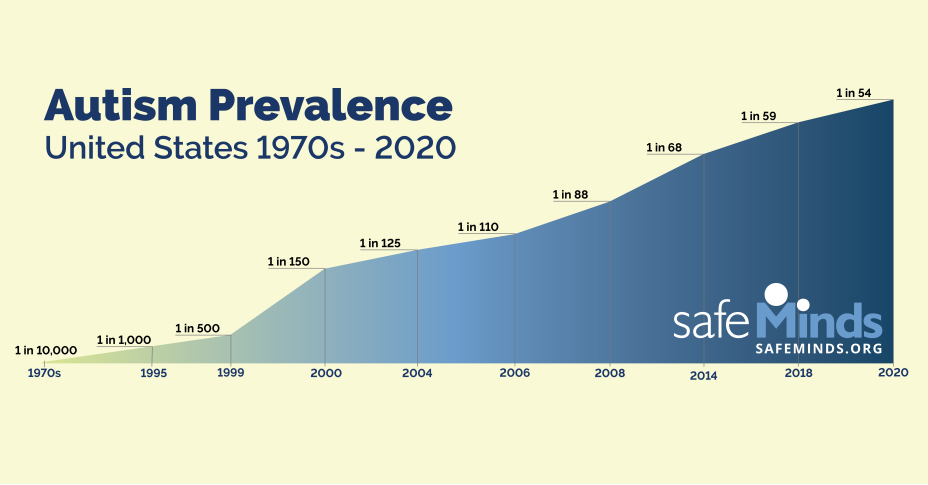


Figure 1.1: Autism prevalence rate through the years - encompasses the entire spectrum of autism [55].

The autism spectrum is often represented as a continuum, with individuals placed at different points along the spectrum based on the severity and combination of their symptoms. At one end of the spectrum, individuals may have fewer challenges and require less support, often referred to as having "high-functioning" autism or Asperger's syndrome, where their communication skills and repetitive behaviors are only noticeable without that support. At the other end, individuals may have more pronounced impairments in multiple areas, requiring substantial support and assistance in their daily lives. However, it is important to note that the autism spectrum is not a linear progression from "mild" to "severe," but rather a complex interplay of various factors and individual differences. In addition, as these labels tend to use a very narrow definition of high- and low-functioning, they can be detrimental for an autistic individual [96]. In Figure 1.2 there is a considerable difference between the two ways of demonstrating the autism spectrum disorder, where the linear one is vague and the circular one is completely focused on the capabilities and challenges of each individual.

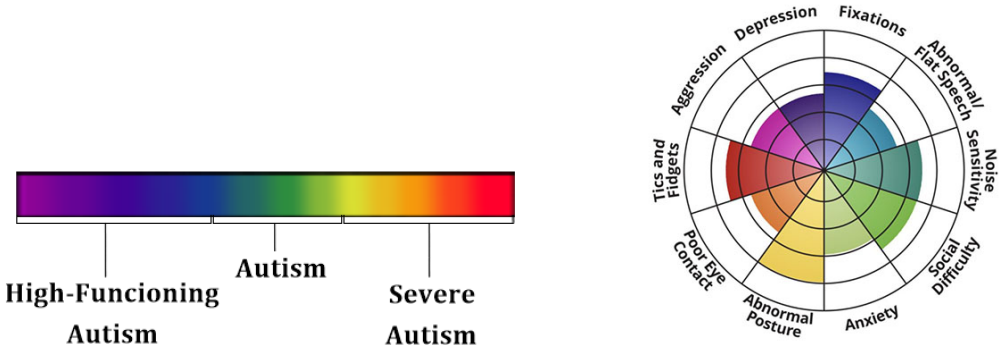


Figure 1.2: Left: Incorrect way of displaying the autism spectrum disorder. Right: Correct way of displaying the spectrum disorder, as it differs from person to person [96].

Experts and professionals use classification system known as Diagnostic and Statistical Manual of Mental Disorders (DSM-5) to diagnose psychiatric illnesses, which contains descriptions, symptoms, and other criteria necessary for diagnosing mental health disorders such as autism [24]. These criteria include persistent deficits in social communication and social interaction, along with restricted, repetitive patterns of behavior, interests, or activities [8]. As symptoms of autism typically emerge in early childhood and can vary in severity and presentation among individuals, it is very important to make an early diagnose because "with earlier identification and a developmentally informed treatment of relatively low intensity significant gains can be made early in life when it seems likely that the potential for change is greatest" [95].

As it is described in the criteria for the classification system and diagnose of autism in [8], social interaction difficulties are a hallmark feature, which may manifest as challenges in forming and maintaining relationships, understanding social cues and norms, and sharing emotions or interests with others. Communication difficulties can range from

delays in speech and language development to challenges in nonverbal communication, such as eye contact, gestures, and facial expressions. Restricted and repetitive behaviors, such as repetitive movements, adherence to routines, and intense interests in specific topics, are also common characteristics of autism.

"Motor problems are not considered a core trait of autism, because they also occur with other conditions" [61], however it is quite common for autistic people to have motor difficulties, in balance and coordination "making it difficult to do actions like pumping their legs on a swing, jumping, skipping or hopping" [61].

Besides motor problems, they can also have visual perception problems, which means that their brain has difficulties in receiving, interpreting and complying with some specific visual stimuli. "Visuospatial perception (VSP) is the ability to appropriately perceive the physical location of an object in relation to the own body and to identify the physical relationship between different objects" [100] and can be divided into: static visuo-spatial perception and dynamic visuo-spatial perception. Static visuo-spatial perception is the ability to perceive and interpret spatial information in a stationary or non-moving context, involving understanding the relationships between objects, their positions, and spatial orientations without any movement, as the example in Figure 1.3. On the other hand, dynamic visuo-spatial perception involves the ability to perceive and interpret spatial information in a context that involves movement, referring to the capacity to understand and process visual information in relation to objects or scenes that are in motion or involve changes in spatial configuration over time.

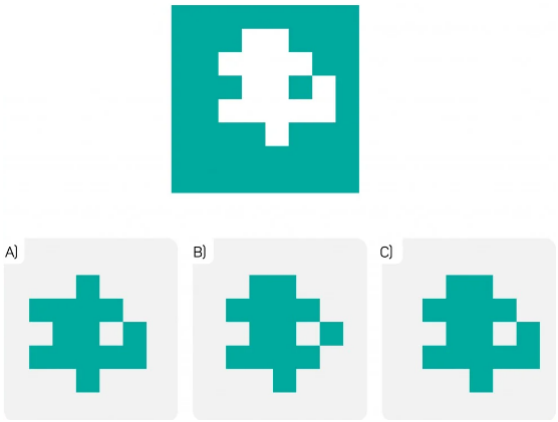


Figure 1.3: An example of static visuo-spatial exercise: select the missing piece to complete the form above [90].

Memory can also be a challenge for some, specially if it implies recalling sentences or stories. However, "Visual memory for some types of material has been found to be an area of strength for children with autism" [97] depending on the complexity of the stimuli. While there are many challenges related to memory, this work will focus on verbal memory, working memory, executive functioning and organization, and sensory processing and memory. "Declarative verbal memory includes the processes of learning new verbal information (i.e., encoding words, facts, stories), storing the verbal information over time (i.e., retention) and, later, overtly recalling or recognizing the verbal information (i.e., retrieval)" [47]. "Working memory is the small amount of information that can be held in mind and used in the execution of cognitive tasks, in contrast with long-

term memory, the vast amount of information saved in one's life" [20], which can impact their ability to process and remember information in real-time for mental calculations, problem-solving or organizing their thoughts during conversations.

Executive dysfunction - "a behavioral symptom that disrupts a person's ability to manage their own thoughts, emotions and actions" [28] - can impact memory in the way that they may struggle with organizing information, planning and executing tasks, prioritizing and managing time effectively, making it harder to encode, store, and retrieve information in a structured and organized manner [58]. Individuals with autism often encounter challenges in processing sensory inputs from various sources like sight, taste, touch, sound, and smell. "Sensory perceptions can become frightening or even painful and can lead to high anxiety and meltdowns" [81]. Consequently, sensory distractions and over-stimulation can further complicate concentration and memory retention for individuals with autism, potentially influencing memory recall and associations.

Besides all the challenges and difficulties they might have, autism also has a profound impact not only on individuals but also on their families. "The experience of parenting a young child with ASD can vary widely and includes both negative and positive aspects, ranging from increased resource needs, to higher levels of parenting-related stress, to positive personal growth for family members" [27]. Families may also face challenges related to accessing appropriate services, navigating educational systems, and managing the emotional and financial burdens [66]. However, with appropriate support and resources, individuals with autism can lead fulfilling lives and make meaningful contributions to their communities.

Considering the above, research plays a crucial role in advancing our understanding of autism, its causes, and effective interventions. Scientists, clinicians, and educators continually strive to identify evidence-based practices that can improve the quality of life for individuals with autism. As we now know, early intervention, therapies focused on social skills development, and communication strategies are among the interventions that have shown promise in supporting individuals with autism. Technology has also shown to be a viable and attractive tool that can be used to motivate them to develop their motor, visual and memory skills.

1.1 Main Objectives

Taking into account some of the mentioned challenges that individuals with autism face every day, the project developed in this dissertation focuses on implementing an interactive system to help them improve some of their capabilities. Therefore, this dissertation has the following objectives:

- Development of four interactive games that target different skills development - memory, visual and motor coordination -, and different types of individuals with autism.
- Integration of a virtual avatar to help and motivate the individual during the use of

the application and during the gameplay, promoting an interactive learning environment.

- Demonstrate that an interactive system with a variety of educational games for specific skill development can have a positive impact on an individual with autism.

1.2 Dissertation Structure

The dissertation is structured as follows:

- **Chapter 1 -** provides the background and context for the study while outlining the research objectives.
- **Chapter 2 -** encompasses a review of relevant literature, explaining some of the project already developed related with autism.
- **Chapter 3 -** gives a comprehensive overview of the methodologies, tools, and software used in the development of the interactive system.
- **Chapter 4 -** explains the development of the interactive system.
- **Chapter 5 -** explains the validation and data collection methods, and it also provides the results obtained and their analyses.
- **Chapter 6 -** presents conclusions drawn from the current work and outlines potential future work.

Chapter 2

Literature Review

2.1 Autism

In 1926, Grunya Efimovna Sukhareva, a child psychiatrist from Kiev that founded a therapeutic school for children with psychiatric problems, wrote and published in a scientific journal a detailed description about autism and their traits [56]. This clinical description was composed of six boys, aged between 2 and 14, and displayed symptoms of what is now known as autism spectrum disorder. She was able to understand the many different behaviours those children had, such as the attachment to a loved one, the fact that some of the children were artistically highly gifted, or musically gifted, or excellent literary gifted. Also, it was and still is possible to understand that if the conditions are favourable, they have the ability to adapt successfully into an environment, proving that a social environment and the correct raising and education is really important and ends up making it possible for them to adapt at school [56] [51].

In her work, she was able to observe multiple details in their behaviour and mannerisms that today are part of the list of the characteristics of a person that has autism, such as the way they keep themselves apart from others - finding it hard to adapt to and can never really be themselves when they are with others - indicating a tendency towards solitude, the lack of facial and movement expressiveness, as well as flatness and superficiality of emotions, repetitious and unusual behavior - repeating the same word or the sensitivity to noise. The description made in her research about the cases she was able to study is recognized as having an amazing precision and modernity, for she already had emphasized the importance of the presence of sensory abnormalities, while that aspect was only recently (2017) able to regain its proper weight in the DSM-5 for the description of ASD, demonstrating how far she already was in the study of autism, as declared in the Journal of Pediatric Neurosciences by Posar and Visconti [72].

About two decades later, Hans Asperger and Leo Kanner published their seminal papers on autism. "While Kanner reported that 3 of his 11 patients did not speak at all, and the remainder rarely used language, Asperger noted that his patients spoke "like little adults" " [69]. Kanner also reported that the children had poor motor coordination but good motor skills, and Asperger observed that in his research both were affected. It was also possible to observe other characteristics, where some are the same as Grunya Efimovna Sukhareva had already described in her publication, but others were related

with high levels of visuospatial skills, muteness or abnormality of speech and fascination with manipulating objects [69].

While these studies date back several decades, it's crucial to recognize their enduring relevance in contemporary autism research. Despite our current understanding of new autism symptoms and related characteristics that have emerged over time, some of the early findings from these studies continue to be applicable to present-day cases [56] [22] [37]. Moving from the fundamental understanding of autism, we now delve into the therapeutic applications based on music and sounds, exploring how these interventions offer promising ways to support individuals with autism.

2.2 The importance of musical therapy

Music therapy (MT) is a therapeutic approach that uses music and musical elements to address physical, emotional, cognitive, and social needs of individuals [3]. It is a creative arts therapy that is practiced by trained music therapists. Music therapy can be used with people of all ages, from infants to older adults, and it can be applied in various settings such as hospitals, schools, and their homes [44]. The goal of music therapy is to facilitate positive changes in an individual's well-being by utilizing the inherent qualities of music [49], which can include doing activities like playing instruments, singing, songwriting, and improvisation [82].

There as been a lot of studies about music therapy in autism throughout the years, where it is evident that music is a positive tool to use with people that have autism to help them express themselves [26]. This music activities can be done in groups or individually and can be handled in either passive (listening) or active (singing, drumming, clapping, dancing) forms [12]. When it is organized in groups, it is easier to help them develop their communication and social skills using music rather that words and making it a fun and enriching experience, while in a calm and controlled environment [26]. Meanwhile, when it is done individually, the music activities are more focused on the development of other capabilities, such as motor skills [26]. Both active music-making and receptive music engagement have cognitive benefits for children with ASD — mainly sustained attention, memory, and enhanced verbal communication [3], and it also helps to alleviate pain, anxiety, agitation, and depression [33].

Besides music, sound therapy, which is the use of individual sounds, is also a valid approach that can achieve great results when working with people with autism, where it can be a more specific treatment depending on the individual [82]. In this type of therapy, they usually focus more on the problem that the person in question has and, taking that into account, they use specific sound frequencies, vibrations or instruments (for example singing bowls and gongs) with the goal of creating a sense of relaxation, balance and harmony within the individual.

Either using music therapy or sound therapy can be a real challenge to obtain the results that we expect from a person with autism, because what might work for one individual might not be the solution for another that appears to have the same type of symptoms, ending up demonstrating that this is a field of research that still has a lot to offer and should continue to be studied. As mentioned before, this therapies should only be done

by professionals of the area and people that have studied and can correctly apply their research on the field. Knowing that, the development of this project will not be focused on the therapy aspect of the studies, but on the positive effects that music and sounds have when used in activities for people with autism. Building on the therapeutic aspect, we transition into the realm of different ways of doing exercise, where we examine how physical activities and technology-based approaches provide avenues for enhancing the well-being and development of individuals on the autism spectrum.

2.3 The benefits of physical exercise and virtual training

Besides the variety of therapies that focus on communication, social and art, physical exercise can also be used as a way of decreasing problem behaviors or increasing appropriate behaviors in the form of exercise therapy, which was already demonstrated by researchers that is very beneficial for individuals with autism spectrum disorder [104]. Physical exercise is recommended to be a part of the everyday life of any person, for it has great health benefits such as reducing blood pressure, improving the quality of sleep, as well as reducing the risk of certain chronic conditions, making it a healthy way to be physically and mentally healthy [80]. "Exercise induces the release of endorphins and monoamine neurotransmitters in the brain, thus mimicking the effects of antidepressants and making physical activity a viable alternative to drug treatments" [80] providing a better option for people to have in their daily lives instead of using treatments that are dependent on pills and not so healthy options.

When people with autism are exposed to physical exercise, it is easy to notice the difficulties that they have at coordination and balance level, which are often associated with the condition [32]. Implementing physical exercise into the routine of an individual with autism brings many advantages such as communication and social development if the exercise is done in group, or in a controlled environment that promotes interaction between people (for example dancing, or a simple high-five) [104]. Physical exercise also helps improving the behavior and body awareness. When individuals with autism are involved in the practice of martial arts such as karate, where they do choreographed movements performed with technical precision in set sequences, it is possible to observe that the participants show positive results in their communication and behavior developments even after one month of the intervention was made, which implies that "learning these karate specific exercise-routines and undergoing the physical exertion that accompanies them has long-lasting effects" [80]. In a sense, standard physical education classes end up lacking the self-awareness and concentration aspects that are inherent in traditional martial arts [80].

While the traditional martial arts or the standard physical exercise can be used to help people with autism develop their capabilities, there is also an alternative that has been studied and achieve a variety of results: virtual training [46] [1]. Virtual training refers to a method of instruction or education that takes place in a virtual or simulated environment rather than in a physical setting, having the advantage of technology to provide interactive and immersive learning experiences [1]. Virtual training can be delivered through various platforms such as computer programs, online courses, virtual reality (VR), aug-

mented reality (AR), or mixed reality (MR) applications [11] [57] [1]. In virtual training, participants can engage in simulated scenarios, environments, or activities that replicate real-life situations [11]. They can interact with virtual objects, characters, or simulations, often using specialized devices such as VR headsets, motion controllers, or haptic feedback systems. The aim is to create an engaging and interactive learning environment that promotes skill development, knowledge acquisition, and performance improvement. This approach of using virtual training has been studied and achieve a variety of results, demonstrating that it can effectively improve the working memory, inhibition, and flexibility, among other skills [46]. As there is no unanimous answer to whether virtual training brings long-term positive results when used as a way of helping people with autism develop their skills, it still needs to be more researched. However, it is possible that when a person with autism is exposed to virtual training, their visual attention, which refers to the cognitive process by which we selectively focus on specific visual stimuli in our environment while filtering out irrelevant or distracting information, improves [45].

This studies and researches about standard physical exercise and virtual training are yet to be more complete, since we still can't exactly tell if there are advantages in using one or another to help people with autism improve their capabilities and overcome their difficulties in the long-term aspect. Knowing that it still is a case that needs to be explored, this project relates to this case of studies in the way that one of the focus of its implementation is a kind of virtual training, where more that one type of training can be used to improve a certain type of difficulties. From physical and technological interventions, we transition into the realm of visual perception, where we explore the intricate process of how individuals with autism may face challenges perceiving and interacting with the visual world.

2.4 The challenge of visual perception

Visual information flows from the primary visual area through various specialized regions, each focusing on different aspects of vision, such as shapes, movements, colors, and depth, ultimately aiding our brains in comprehending the visual world [70]. Within the realm of visual perception, two important components are: visual spatial skills and visual coordination. Visual spatial skills refer to the ability to understand and perceive spatial relationships, orientations, and arrangements of objects in the visual field [70]. These skills encompass spatial awareness, mental rotation, spatial visualization, and spatial reasoning. They enable individuals to mentally manipulate and navigate objects in space, solve spatial puzzles, and comprehend maps and directions. Visual coordination, on the other hand, involves the integration and coordination of visual information from both eyes, facilitating smooth and accurate eye movements, depth perception, and visual tracking [16]. Knowing that, visual spatial skills and visual coordination play crucial roles in visual perception, since visual spatial skills contribute to our understanding of spatial relationships and the organization of objects in the visual field, and visual coordination ensures that our eyes work together effectively to perceive and track visual information accurately [102] [16]. By combining these components, individuals can form a comprehensive understanding of the visual world and interact with it efficiently.

Saying that every person with autism has the same level of visual perception difficulties is not correct, because each individual is different and it's natural that some researches about the subject present results where they accomplished the goal they set, which was helping the development of people with autism in that area, and other studies didn't. The variability in findings across existing literature has been linked to diverse sample demographics and clinical descriptions of diagnostic groups, varying task requirements, discrepancies in task administration, and differences in stimulus properties [23] [102]. Typically, these studies employ research paradigms that involve individuals identifying smaller shapes within larger, more intricate shapes from a limited set, or sorting objects/stimuli based on local versus global features, "however, some of the previously used paradigms may lack the precision necessary to relate individual differences in performance to ASD traits" [23].

Some studies involve the development of projects where they focus their attention on eye tracking, integrating the analysis of their motor capabilities [98] or connecting the relation between visual attention, a component of visual perception, and social and communication development [101]. The goal of this researches is to understand how attention and action are coordinated during the different types of experiences that groups with and without ASD are exposed to. This study [98] concluded that there were no differences between both groups in terms of visual attention, meaning that it could be one of the cases where the group with ASD could have better visual perception skills that others or that the type of experiment isn't the ideal one where they could see their real difficulties in terms of visual perception.

The development of this project for the visual perception part doesn't include eye tracking, but rather body tracking were they need to move accordingly to what they see on the screen, making it a different way to explore their visual perception capabilities. Continuing our exploration of cognitive processes, we now delve into the subject of memory, which make a very important part of the daily life of an individual with autism, examining both its strengths and challenges.

2.5 The importance of memory in our daily lives

Memory is a fundamental cognitive process and plays a significant role in our daily lives, encompassing various aspects such as storing, retaining, and recalling information [86]. One notable aspect of memory in autism is the presence of "islands of expertise" or "savant skills." Some individuals with ASD demonstrate exceptional memory abilities in specific domains. For instance, they may possess remarkable rote memory skills, being able to recall vast amounts of information with great precision, while others may have extraordinary attention to detail, noticing and remembering minute features that often go unnoticed by others.

"Episodic memory includes encoding of contextual features (location, time of event) associated with the event itself, which allow us to distinguish events from one another at retrieval" [48]. Some individuals may struggle with recalling specific details of past events or providing detailed personal narratives, which can affect their ability to construct a coherent narrative of their experiences. However, others may demonstrate intact or even

enhanced episodic memory abilities, showcasing vivid recall of past events.

Working memory, a crucial component of cognitive processing, may present challenges for individuals with ASD [102] [77]. Since working memory involves temporarily holding and manipulating information for ongoing cognitive tasks, individuals with autism can experience difficulties in working memory such as their ability to remember and manipulate information in their mind, follow multi-step instructions, or solve complex problems [77].

From the researches done in the topic of memory with individuals that have autism is important to note that memory strengths and challenges can vary widely among them. Factors such as intellectual abilities, age, language skills, and individual characteristics can influence their memory profile. Understanding an individual's unique memory strengths and challenges is essential for tailoring interventions and supports to their specific needs, maximizing their learning potential, and facilitating their overall cognitive development. Transitioning from the topic of memory, we have the incorporation of technology in the routine of an individual with autism, besides using it for virtual training as mentioned before, where we explore how modern tools and digital solutions are transforming support mechanisms and interventions for individuals with autism.

2.6 Incorporation of technology as an educational tool

Technology has emerged as a powerful tool in the realm of ASD, providing various avenues of support for individuals across different aspects of their lives [101] [98] [16] [45] [1] [11] [46]. As it was already demonstrated in the mentioned studies and researches, the intersection of technology and autism offers promising opportunities for enhancing communication, social skills, education, sensory integration, behavior management, and access to support networks. Augmentative and alternative communication (AAC) devices and apps serve as valuable tools, enabling individuals with ASD to express themselves and engage in meaningful interactions [40]. Technology also presents innovative possibilities for social skills training [71] [2]. Virtual reality (VR) and augmented reality (AR) technologies provide immersive and interactive environments where individuals can practice social interactions [1]. Simulated scenarios with virtual characters or avatars offer a safe space for individuals to develop social skills, receive social cues, and gain feedback, ultimately fostering generalization to real-life social situations [30].

"According to the latest insights as to how exactly modern students of today prefer to use technology and how does their learning get an impact if they use technology, it was revealed that the use of modern equipment technology and tools, the learning and interactivity of students increases" [74]. Sensory integration and regulation are significant areas of concern for individuals with ASD, and technology can address these challenges, as in this studies [98] [16], which also showed that it has great potential to practice social skills in a calm and safe environment [53]. Technology also contributes to behavior management strategies for individuals with ASD, allowing them to be more self-sufficient [83]. These technologies allow individuals with ASD and their caregivers and educators to enhance the daily life social behaviours of individuals with autism [11].

While technology holds great promise, it is essential to consider its implementation thoughtfully, as technology-based interventions should be carefully developed to meet

the specific needs and preferences of individuals with ASD, since they can have very different characteristics and challenges that vary from individual to individual.

Chapter 3

Methodology and Development Tools

3.1 Methodology

After reviewing the literature on the many concepts, and also the variety of projects that were already developed to help individuals with autism increase their knowledge and skills, it was important to think on how to incorporate all of that and make a useful application. The methodology behind the development of this project can be divided in the following questions:

- How to integrate a way of helping them develop their skills, using technology, without it being annoying or boring?
- How should we present the information on how to use the technology?
- Should the individual interact with it using a controller or be free to move?
- Is it better if the individual is using it alone in silence or with someone to help them, give them feedback and motivation?

During the development of this project, there were more questions to be answered, but it was this first ones that initiated it. By firstly focusing on the first and third questions, we took into consideration the great diversity that individuals with autism can have in terms of their capabilities and challenges, and ended up creating four types of interactive games, each more challenging than the other. Each of these four interactive games work a different set of skills or has a different way of working a certain type of skills. Besides, and looking at the fourth question, we considered that it would be beneficial to incorporate a 3D avatar during the gameplay that would mark its presence by giving feedback and providing motivation to the user.

First Game

In this game, the aim is to enhance memory, visual perception and attention, and motor coordination. This first game presents the player with an engaging challenge of matching pairs of images, that consists of a shell and a pearl of the same color, as in Figure 3.1.

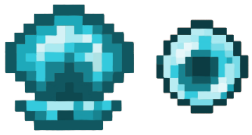


Figure 3.1: Example of a pair: shell and pearl of the same color.

The objective is to remember and recreate a sequence of pairs of images, each associated with a unique sound, as the rounds progress in complexity. At the start, a single image appears, but with each round, the sequence grows. The player's coordination and motor skills come into play as they simultaneously select both the shell and its corresponding pearl, aligning with the accompanying sound. The left hand selects the shell, while the right hand selects the corresponding pearl, forming a synchronization of sight and touch.

To help the user understand the result of each of their gameplays during the game, there is also feedback given in the form of voice, by the avatar, and in the form of sounds, whether they got it right or wrong. The player has three lives at their disposal, and with each incorrect sequence, they lose a life. To succeed, they must replicate the exact order of images and their sounds. Mastery of the sequence earns points, while mistakes lead to the loss of points and lives, underscoring the significance of precision and focus.

As the game progresses and the complexity increases, players develop their memory, concentration - visual perception and attention -, and hand coordination skills, ensuring constant growth and presenting a satisfying challenge for the users. Figures 3.2 and 3.3 exemplify how this game is played.

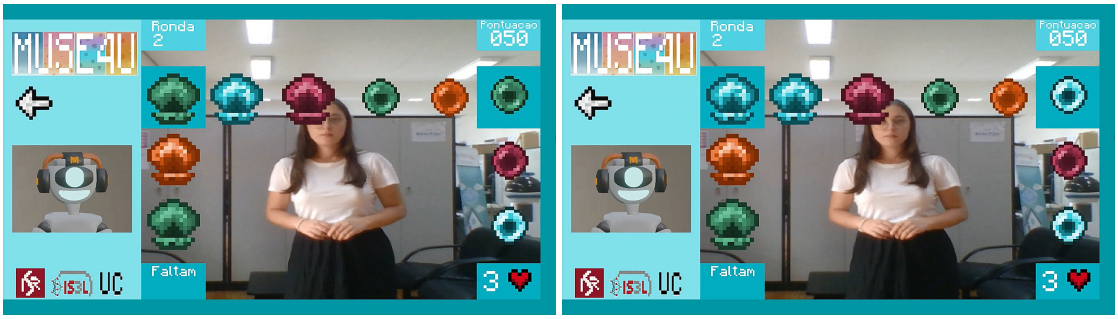


Figure 3.2: This is an example of how the sequence, of round 2, of pairs could be in this game and how it is displayed to the individual that would be playing the game. Left: First pair of the sequence. Right: Second pair of the sequence.

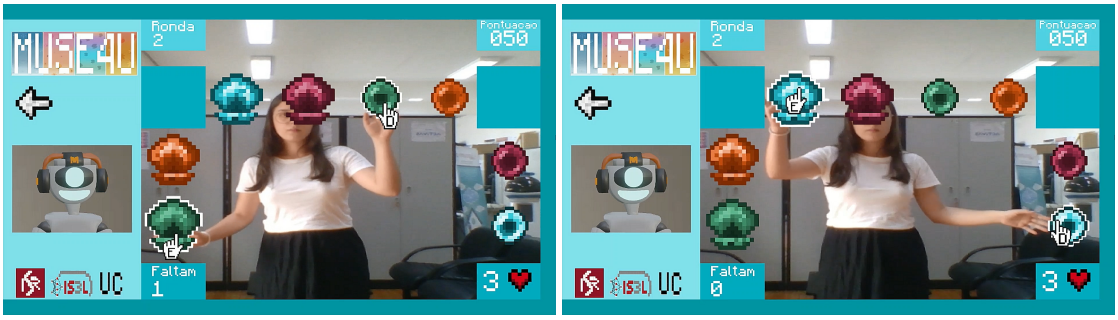


Figure 3.3: This is an example of how the individual would have to play in order to win that round. Left: Selecting the first pair of the sequence. Right: Selecting the second pair of the sequence.

Second Game

The main objective of this second game is to enhance visual and motor coordination by utilizing specific body parts, each linked to colorful sprites on the screen. Players are invited to use their elbows and feet to guide the caterpillars of corresponding colors – red for the left elbow, green for the right elbow, and yellow for both feet – to touch the leaves of matching colors that flutter across the screen. Figure 3.4 is one of the matches that can be done in this game.

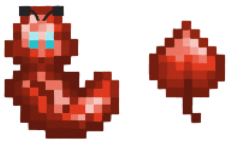


Figure 3.4: Example of a match: red caterpillar and a red leaf.

Unlike the previous game, this one operates with a ticking timer rather than rounds. Players must swiftly and skillfully navigate their caterpillars to collect as many leaves as possible before time runs out. But there's a twist – if any of the caterpillars mistakenly touch the colorless leaf, points will be deducted from the respective caterpillar's score. Time bonuses occasionally appear alongside the leaves, granting an additional ten seconds on the timer when captured.

The game also has background music, creating a comfortable environment for the user to enjoy. The friendly avatar lends its encouraging voice as feedback throughout the game, ensuring players feel supported and motivated. Meanwhile, satisfying sound effects accompany every successful leaf or bonus capture, or touch of the colorless leaf. Figure 3.5 represents the possible gameplay of this game.

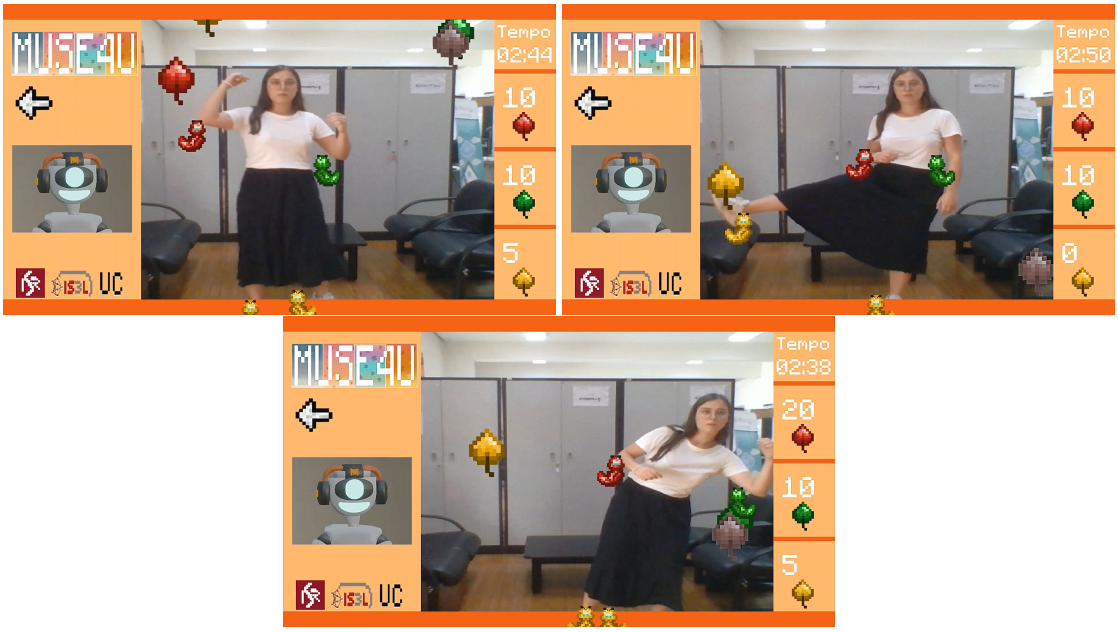


Figure 3.5: This is an example of how the individual would have to play in order to catch the leafs with the respective associated body parts.

Third Game

The objective of the third game is to improve visual coordination, by associating images linked to certain parts of the body - the torso and knees - with images that appear on the screen. Additionally, it aims to enhance motor coordination through knee lifts and squats, promoting physical exercise. The user controls a bee located in the lower area of their torso, and the goal is to guide the bee to touch the flowers that appear on the screen. Figure 3.6 displays the correspondent matches of sprites for this game.

Figure 3.6: Left: Sprites that correspond to the bee and the flowers. Right: Sprites that correspond to the wasp and shield.

In this game, the user will encounter not only flowers but also wasps. To interact with the sprites passing on the screen, the user must use specific body movements indicated at the top of the screen. For example, when flowers appear, a bee icon will be displayed at the top, and when wasps approach, a shield icon will appear. The user can either avoid wasps through body movements or use the knee shields to defend the bee from them, gaining points. Points are also earned for each flower picked up by the bee, while points

are deducted when a wasp touches the bee. As the game advances through rounds, the speed at which the sprites cross the screen increases accordingly.

The game features background music and various sound effects associated with the appearance of wasps on the screen, feedback when a wasp touches a bee, and when a shield touches a wasp, as well as when the bee touches a flower. When the wasps are coming, the avatar also alerts the user to be careful and motivates the player to give their best. Figure 3.7 provides an example on how to play this game.

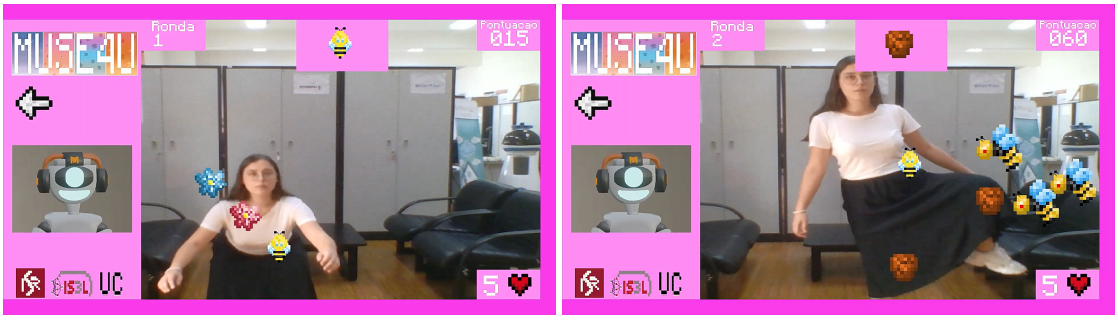


Figure 3.7: This is an example of how the individual would have to play in order to catch the flowers with the bee, and defend from the wasps with the shield.

Fourth Game

In the fourth game, the main focus is on training motor and visual coordination. The user must associate the sprites linked to their hands with the actions that randomly appear on the screen. In this game, the user holds a Christmas candy in their right hand and a tool in their left hand. On the screen, there are sprites depicting Christmas lights in four different colors. All of this sprites are displayed in Figure 3.8

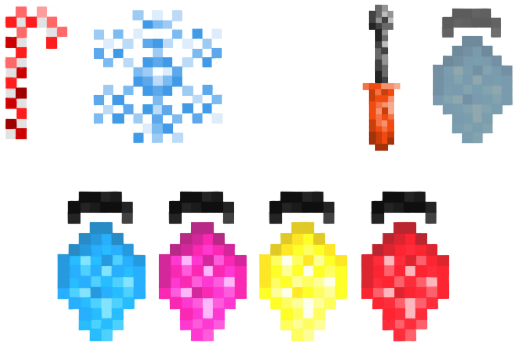


Figure 3.8: Top left: Christmas candy that is used for the snowflake. Top right: tool that is used to fix the light. Below: Lamps with the lights on.

When a Christmas light freezes with a snowflake above it, the user needs to break the ice using the Christmas candy (right hand). Conversely, when a pair of lights stop working and appears as a pair of blown light bulb, the user must fix either of them using the tool (left hand). The game progresses in rounds, with increasing difficulty as the time given to complete each task decreases.

The challenge lies in completing the tasks quickly and accurately. If the user fails any of the tasks five times, the game ends, and the remaining chances are represented as lives. Background music sets the atmosphere, and feedback sounds indicate when a light bulb freezes, is blown, defrosts, or gets repaired, as well as feedback given from the avatar to alert when the time to complete the two tasks is almost over. Figure 3.9 exemplifies the gameplay for this game.

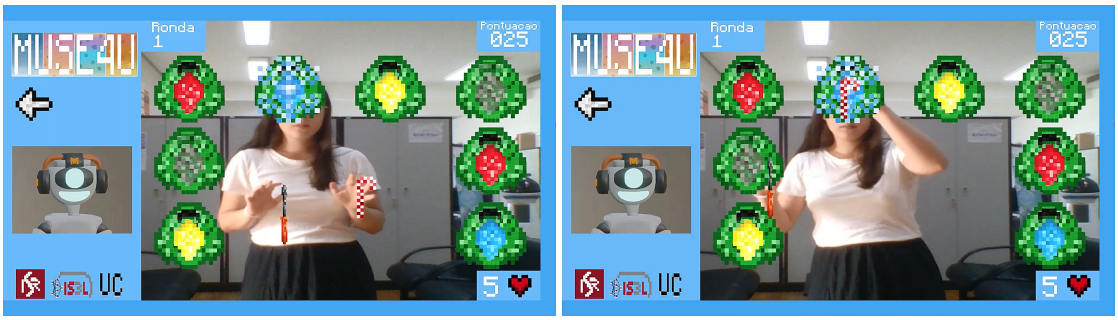


Figure 3.9: This is an example of how the individual would have to play in order to catch the break the ice that appears randomly in one of the lights, and fix the pair of lights that randomly goes out.

Information Menus

Regarding the second and fourth questions, we came to the conclusion that designing an information menu that could display more than one way of explaining how the game is played would be beneficial for the individual. Besides, we also considered that one of the ways to display the visual information on those information menus would be with the help of a 3D avatar.

Figure 3.10: Information menu for the first game.

For individuals with autism, gradual learning and progression are vital. Information menus allow users to revisit instructions whenever needed, reinforcing learning and skill-building over time. This accessibility promotes a sense of achievement and a desire to

continue exploring the app's games. The information menus were all created in the same way, as it is displayed in Figure 3.10, and can all be seen in Appendix A. The voice lines of the avatar in each of the menus are all listed in Appendix E.

Game Mode

As autism is a spectrum, it was important to create a gaming experience that would be inclusive and engaging for all users, while also targeting specific difficulties they might face. To achieve this, it was incorporated two distinct game modes - "Train" and "Game" - each offering a different approach to gameplay, as it can be see in Figure 3.11.

Within "Train" mode, users play for a limited number of rounds or a specific duration, depending on the game. This allows users to focus on mastering specific aspects of gameplay without feeling overwhelmed. By emphasizing skill development, "Train" mode creates a supportive environment for users to have a better understanding of what the game in question is about, learn and refine their abilities. It serves as a good starting point for those who are new to the app or wish to build a solid foundation before delving into the more challenging aspects of the game.

In "Game" mode, users can keep playing until the time runs out (in time-based games) or until they run out of lives (in rounds-based games). This feature provides an uninterrupted gameplay that continuously challenges and motivates users. "Game" mode caters to the competitive spirit of users, challenging them to achieve higher scores and better performances.

Figure 3.11: Menu to select the game mode.

Leaderboard

Besides using a virtual helper to keep the individual motivated, a leaderboard system was integrated to serve as a way of displaying the achievements of users who have opted for the more challenging and competitive "Game" mode. The leaderboard showcases the 8 highest scores and best performances of users who have engaged in the "Game" mode, giving a special visual display for the three best scores in the game in question.

By having their names displayed on the leaderboard, users are encouraged to participate in friendly competition with themselves and others. It motivates them to improve

their performance, beat their personal bests, and aim for higher rankings on the leaderboard. For individuals with autism, achieving milestones and setting personal records can be especially significant. The leaderboard provides a tangible representation of their progress and accomplishments, fostering a sense of pride and satisfaction in their gaming journey. In Figure 3.12, on the left side displays the leaderboard that appears at the end of "game" mode, and on the right side displays the leaderboard that can be seen outside of the games, in a separated menu that is accessible from the main menu.

Figure 3.12: Left: Leaderboard that appears at the end of the game, where the user has the possibility (if in game mode) to input their name on the table. Right: Leaderboard that the user can access from the main menu.

In order to develop this interactive system, it was necessary to choose the correct tools that would make it fun and enjoyable to use. This next section explores the various tools that were utilized during the development of the app, encompassing the essential software and technologies that facilitated the realization of this project.

3.2 Development Tools

One of the central pillars of this app development was the utilization of Blender, a renowned 3D modeling and animation software. Blender played a pivotal role as it was created a lifelike and empathetic 3D avatar, serving as a supportive guide throughout the app's games. While its robust features enabled me to meticulously design and texture the avatar, the development process also incorporated motion capture technology, a cutting-edge tool used to capture and record real-life movements for integration into the avatar's animations, bringing the avatar to life with natural movements. This advanced technology, combined with Blender's animation capabilities, contributed to the app's immersive and interactive nature, enhancing users' engagement and motivation.

To ensure a dynamic and responsive user experience, Python was used, a versatile and widely-used programming language, for the app's development. Python's efficiency and flexibility allowed the implementation of interactive elements, design engaging gameplay, and optimize the app's performance for a seamless user journey.

Throughout this section, the aim is to provide a comprehensive overview of the app development tools that were utilized in the creation of this interactive and empowering app. By leveraging the power of Blender, Python, and Motion Capture technology, it

was possible to achieved the objective of developing an inclusive and supportive app that fosters the development of motor, visual, and memory skills for individuals with autism.

3.2.1 Blender

Blender is known as a free and open-source 3D creation suite renowned for its versatility and robust capabilities. With a dedicated community of artists, animators, and developers, Blender allows us to work "with almost all possibilities within 3D modeling, animation, application of materials, lights, rendering, etc" [59]. This section explores the key features that make Blender stand out as a powerful software for 3D content creation.

One of Blender's key strengths is its diverse selection of primitive shapes, including cubes, spheres, and cylinders, which serve as a starting point for building more complex objects. Users can easily shape and refine the created models by manipulating vertices, edges, and faces with features like extrusion, beveling, and loop cuts. Blender's modifier system allows for non-destructive modeling, as users can apply various modifiers to their mesh objects. This flexibility enables efficient workflow and makes it easy to experiment with different design iterations. Sculpting tools in Blender offer the ability to add intricate details and organic shapes to models, making it a viable choice for character and creature modeling. With dynamic topology and a variety of brush types, artists can achieve highly detailed and realistic 3D models. The results of using those tools can be seen in the example displayed in Figure 3.13

Vertex paint tools allow artists to paint directly on the vertices of their models, offering an intuitive way to add colors, blend textures, and create unique visual effects, which can be very helpful for research and education purposes [6]. Additionally, "add-ons add new or improved functionality to Blender" [99], enhancing the modeling process with additional tools, scripts, and workflows, catering to specific requirements and allowing users to customize Blender to their needs.

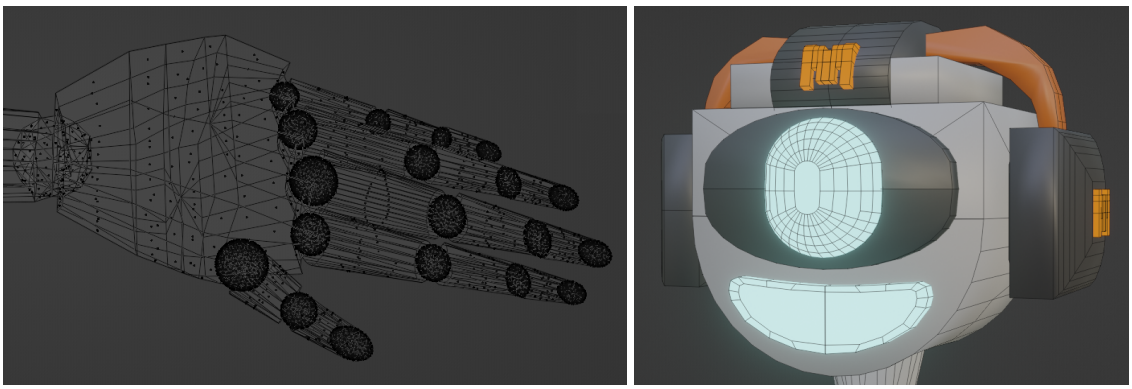


Figure 3.13: Left: The shape of a hand made in Blender. Right: Painted mesh using Blender tools.

For character animation, Blender offers a robust rigging system that involves creating a skeleton (armature) within the 3D model and assigning it to the mesh. So, "rigging is the process of creating the armature and the "gluing" (assigning parts of the mesh to particular "bones" of the armature)" [84], ensuring that the mesh moves naturally in

response to bone movements. Blender provides a variety of rigging options, including inverse kinematics (IK) and forward kinematics (FK), giving animators the flexibility to choose the most suitable method for their animation needs. Rigging add-ons, such as Rigify, automate the rigging process, making it easier for artists to set up complex rigs quickly.

Motion capture integration is another powerful capability in Blender's animation toolkit. Motion capture data can be imported into Blender and mapped to the rig, allowing for realistic and natural character animations [43]. This integration enhances the animation process, enabling animators to achieve lifelike movements with ease. Blender's animation system supports various animation techniques, including character animation, object animation, and camera animation. With the ability to animate multiple elements within a scene, Blender offers a comprehensive solution for creating engaging and visually captivating animations.

Blender's multifaceted nature makes it an all-encompassing 3D creation suite that caters to artists, animators, game developers, VFX professionals, and hobbyists alike. Its robust modeling, animation, rendering, and video editing tools, along with a flexible user interface, contribute to its widespread popularity and position it as a leading software for 3D content creation in various industries.

3.2.2 Rigging

Rigging is an essential process in 3D animation and computer graphics, which can be defined as "the process of creating skeleton system inside the character" [4], also known as an armature, giving life and flexibility to 3D models. This armature allows the model to move and react to various poses, animations, and interactions.

At the heart of rigging are "bones," which act as the framework of the armature and are similar to the joints in a human skeleton, as it is in Figure 3.14. These bones serve as anchor points for deformation and determine how the model bends and moves. Usually, the main task that a rigger artist needs to do is "to develop a skeleton system that consists of bone object, assign controller for each bone and skinning the 3D mesh which is defined as the process of attaching character limbs to the bones" [4], influencing how they move during animation.

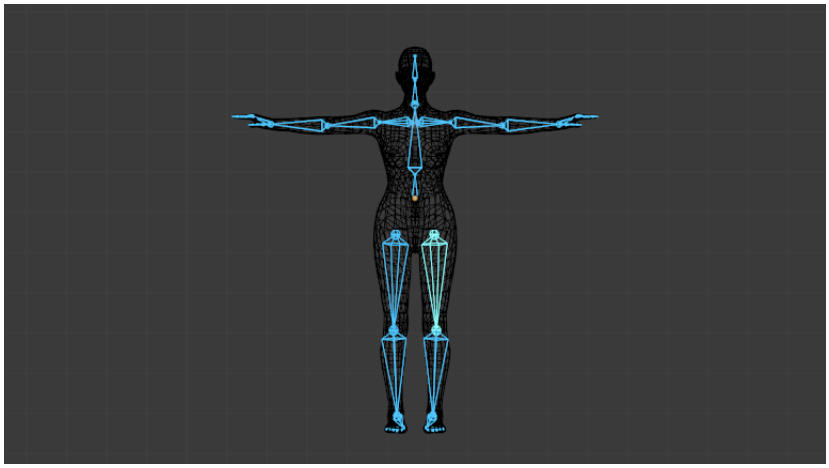


Figure 3.14: An armature made for a 3D avatar in Blender [42].

Riggers employ two key techniques in rigging: forward kinematics (FK) and inverse kinematics (IK). With FK, riggers can individually, and hierarchically, manipulate each bone to control the entire armature's motion, offering precise control over specific parts of the 3D model [4]. On the left side of Figure 3.15, a simple chain of bones simulates a complete leg, where the bones are controlled from the root (typically the parent bone) to the tip (child bone), being that when the parent bone is moved or rotated, all the child bones in the chain follow accordingly. This setup is often used for simple and predictable animations.

In contrast, IK allows animators to control a chain of bones by manipulating a single bone at the end, in other words the bones are controlled from the tip to the root, making complex movements more manageable [4]. The animator manipulates the end bone (e.g., hand or foot), and the rest of the bones in the chain automatically adjust to maintain the desired position of the end effector. This approach is particularly useful for complex animations where you want to achieve precise positioning or interactions with objects in the scene. The example on the right side of Figure 3.15 illustrates the rigging process for a leg, starting with a chain of bones representing the entire leg and, to facilitate inverse kinematics, two helper bones are introduced – one for the foot and one for the knee -, that will be used to control the chain of bones previously created.

Strategically placed, these helper bones control the other bones in the rig in a cascading manner, starting from the lowermost bone and moving upwards, contrary to the usual top-to-bottom control approach. This setup allows for smoother and more intuitive manipulation of the leg during animation, enhancing the overall rig's flexibility and ease of use.

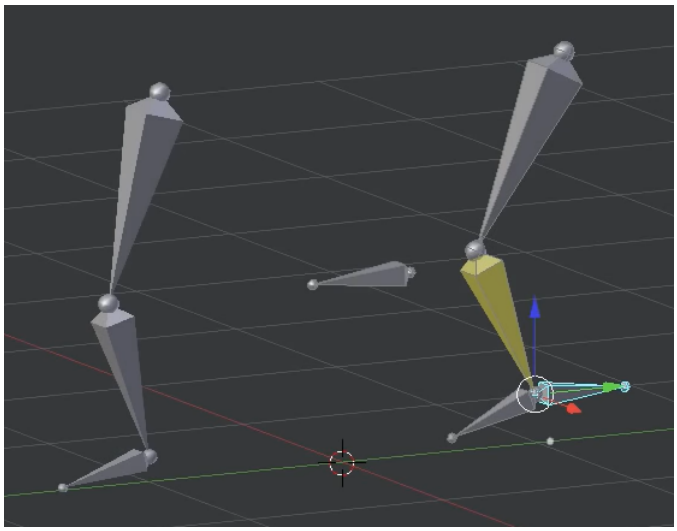


Figure 3.15: The chain of bones on the left side of the image were implemented with FK and the chain of bones on the right side of the image were implemented with IK [29].

Rigify is a powerful add-on in Blender that "is used to help automate the rigging process and it is highly flexible on what it can do" [35], making it more efficient and user-friendly. It provides a collection of pre-built rig templates, including FK and IK controls, to rig characters quickly and easily, as it is demonstrated in Figure 3.16. When using Rigify, constraints are automatically applied to the armature to enable various control

mechanisms. Constraints are rules that define how bones should behave in relation to each other or other objects in the scene, allowing for complex interactions between bones and enabling the creation of sophisticated rigging setups.

For example, Rigify typically uses "Copy Rotation" constraints to mimic the rotation of one bone with another bone. This is useful for replicating natural movements, where the rotation of one bone, such as the upper arm, influences the rotation of another bone, like the forearm.

Rigify's comprehensive library of constraints provides animators and riggers with a wide range of possibilities to create rigs that suit their specific needs. By streamlining the rigging process and offering a multitude of control options, Rigify simplifies the task of character rigging, saving time and effort while achieving professional-quality results.

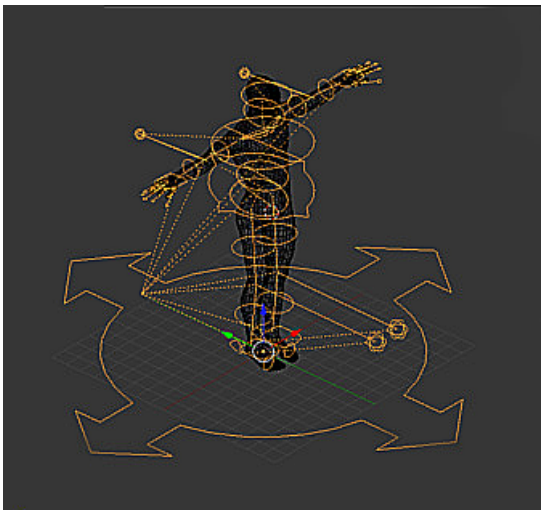


Figure 3.16: Using Rigify to apply constraints to the armature in Blender [88].

While specific rigging techniques may vary among different 3D software packages, the core principles remain consistent. Rigging is both a complex and rewarding process that empowers animators to breathe life into their creations, bringing their imagination to life in the virtual world.

3.2.3 Motion Capture

Motion capture, commonly known as mocap, is a powerful and versatile technique used in animation, film making, virtual reality, and various other industries to capture and record real-world movements [4] [5]. The process involves tracking the motion of people, objects, or animals and then remapping that data to digital characters or models [4]. By capturing the intricacies of human movement, motion capture enhances the realism and performance of virtual characters, providing a more immersive and authentic experience for audiences. It plays a vital role in sports analysis, providing valuable insights into athletes' movements and performance, and, "from a biomechanical perspective, motion capture is the primary source of data that helps researchers to gain knowledge of the mechanics governing human movement" [65]. Motion capture systems utilize various technologies and methods to track movements, catering to different needs and applica-

tions.

Optical Motion Capture (or marker-based motion capture):

- Considered the gold standard in biomechanics, this method employs infrared cameras and reflective markers placed on the subject's body or objects of interest to triangulate their 3D position [65].
- The cameras capture the movement of markers in real-time, providing highly accurate data for precise 3D representation of the subject's motions [65].
- Optical motion capture is widely used in the entertainment industry for creating realistic character animations in video games and films, as well as in biomechanical research and sports analysis [65] [5], where Figure 3.17 is an example of that.

Figure 3.17: Example of how the optical motion capture is used for an animation in a movie [31].

Inertial Motion Capture:

- Inertial measurement units (IMUs) "overcome the limitations typical of optical motion capture systems, e.g. occlusion and illumination problems" [50].
- IMUs contain accelerometers and gyroscopes, and they are attached to the subject's body to measure motion data directly [65] [85], as exemplified in Figure 3.18.
- "These systems are gaining more and more attention because of their low price, portability, and relatively low maintenance" [50].

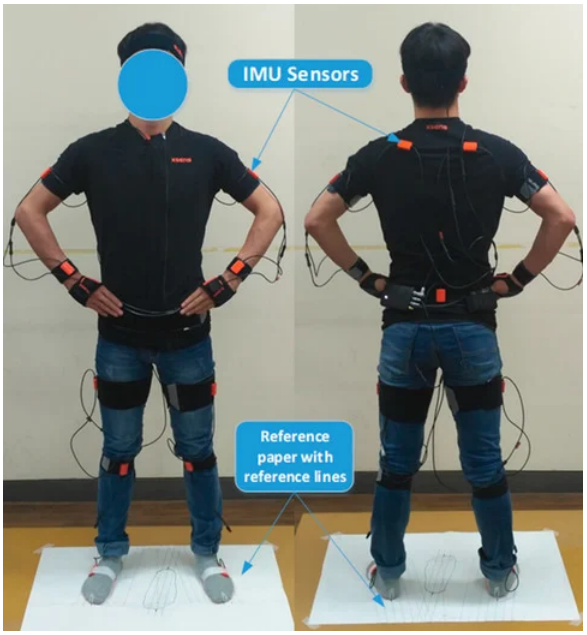


Figure 3.18: Example of how the inertial motion capture works [34].

Depth-Sensing Motion Capture:

- Depth-sensing cameras, like Microsoft's Kinect, are used in this method to capture depth information of a scene [17].
- By analyzing the depth data and tracking the subject's movements, this technique achieves motion capture without the need for markers or specialized suits, where "depth images generated by depth cameras are shown to be insensitive to lighting changes and have led to gaining high performance in human action recognition" [17]. Figure 3.19 is an example of this technique.

Figure 3.19: Example of how depth information is captured without markers in motion capture [38].

Each type of motion capture system has its strengths and limitations, making them suitable for different scenarios. Optical motion capture excels in capturing precise details,

but it can be a time-consuming process and may have higher setup costs [65]. Inertial motion capture offers portability but might not achieve the same level of accuracy as optical systems for now [105]. Depth-sensing motion capture is more flexible and markerless but may have limitations in capturing fine details, as it requires slower movements [105]. However, there has been studies that use both depth sensors and inertial sensors to try and overcome those limitations [105].

Data Processing

Data processing is a crucial step in motion capture, where the raw motion data, that is usually contaminated with noises from different sources, is collected from various sensors and cameras, and used to generate high-quality motion signals [60]. This processing stage normally involves a series of algorithms and techniques to clean, synchronize, and refine the captured data for accurate representation and analysis.

Data Cleaning - During the capture process, sensors and cameras can introduce errors, leading to unwanted artifacts in the motion data. "Marker trajectories must not contain any gaps, and the markers need to be properly labeled at every time step, something that is not always guaranteed by the motion capture system" [21]. Data cleaning algorithms are employed to remove outliers, filter noise, and correct any discrepancies. This step ensures that the final motion data is more reliable and free from unwanted disturbances.

Data Synchronization - Different sensors might have slight timing differences, resulting in misaligned data streams. Data synchronization algorithms align the timestamps of the captured data to match precisely, creating a coherent representation of the subject's movements across all sensors or cameras [13]. "Accurate synchronization of the different data streams is crucial for time-critical analysis of the data and for relating the different data streams to each other in order to answer the research questions at hand" [13].

Data Calibration - For optical motion capture systems that use markers, a calibration process is necessary to establish the correspondence between the marker positions and the subject's body segments accurately. "The main purpose of the calibration stage is to create a relative 3D reference for each camera so that each camera has a its own reference in 3D space relative to the other cameras" [41], enabling the accurate reconstruction of the subject's pose from the marker data.

Data Reconstruction - Once the motion data is cleaned, synchronized, and calibrated, it needs to be reconstructed into a coherent skeletal representation. Human motion reconstruction involves recording real subject motion using a motion capture system, adjusting a digital human model's geometric dimensions based on subject-specific parameters, and then reconstructing the model's motion using various inverse kinematics techniques from measured motion data [7]. This reconstruction process allows for the generation of realistic animations and movements.

Data Smoothing- Motion capture data can often be discrete and captured at a fixed

frame rate. To create smooth and natural animations, data smoothing techniques are applied "to improve quality of playback at a later stage, or to obtain a more accurate estimation of position and velocity of a marker, which may allow for more accurate estimation of its position during periods of marker occlusion" [78]. Smoothing algorithms help eliminate sudden jitters and jerky movements, resulting in more lifelike animations.

Data Analysis and Interpretation - The processed motion data serves as a rich source of information for various applications. Researchers, animators, and developers use data analysis tools and software to interpret the motion data and extract valuable insights. This analysis can involve identifying key movements, measuring joint angles, calculating velocity, and studying motion patterns for animation, virtual reality, and sports analysis [79].

The accuracy and quality of the processed motion data directly influence the realism and effectiveness of the final animations and applications. As motion capture technology advances, data processing techniques continue to evolve, enabling more accurate, efficient, and versatile motion capture solutions for a wide range of industries and creative endeavors.

While motion capture offers numerous benefits, it also presents challenges and limitations. The cost of motion capture systems, specialized equipment, and skilled personnel can be substantial, making it more accessible to large-scale productions or well-funded research projects [65]. "These devices are typically used in controlled environments to record short or medium-sized motion sequences, each containing one or several semantic actions" [79]. The need for a controlled environment and proper calibration is crucial to ensure the reliability and accuracy of the captured data.

3.2.4 Python

In the last few years, python has become one of the most popular programming languages because of its flexibility. It can easily "incorporate object-oriented, imperative, functional and procedural programming paradigms with an enriched comprehensive standard library" [89]. In this subsection, it is explored some of Python's noteworthy libraries that facilitate sound processing, image capture, and body detection.

Interaction

Pygame: "is a module for the Python programming language that allows users to develop game applications and create games with distinctive features" [63]. Its blend of simplicity and versatility makes it an ideal medium for developers to bring imaginative concepts to life, turning code into captivating narratives. Pygame's advantages effectively address diverse game development requirements by offering abundant resources, enhancing work efficiency, expediting development cycles, and lowering costs [18].

Sound Processing

MIDI (Musical Instrument Digital Interface): is a protocol that enables computers and electronic musical instruments to communicate with each other. "MIDI data consist of

variables describing musical events, such as a note's name, its velocity of activation by a controller key,and its channel assignment" [19]. MIDI is versatile, allowing seamless integration of various musical devices, making it essential in music production and live performances. It empowers musicians to create, edit, and arrange compositions, offering precise control and real-time manipulation. It also has a vast range of instruments to simulate the sound that is emitted, as it is in Figure 3.20.

Piano Timbres:	Chromatic Percussion:	Organ Timbres:	Pipe Timbres:	Synth Lead:	Synth Pad:
0 Acoustic Grand Piano	8 Celesta	16 Hammond Organ	72 Piccolo	80 Square Wave Lead	88 New Age Pad
1 Bright Acoustic Piano	9 Glockenspiel	17 Percussive Organ	73 Flute	81 Sawtooth Wave Lead	89 Warm Pad
2 Electric Grand Piano	10 Music Box	18 Rock Organ	74 Recorder	82 Calliope Lead	90 Polysynth Pad
3 Honky-tonk Piano	11 Vibraphone	19 Church Organ	75 Pan Flute	83 Chiff Lead	91 Choir Pad
4 Rhodes Piano	12 Marimba	20 Reed Organ	76 Bottle Blow	84 Charang Lead	92 Bowed Pad
5 Chorused Piano	13 Xylophone	21 Accordion	77 Shakuhachi	85 Voice Lead	93 Metallic Pad
6 Harpsichord	14 Tubular Bells	22 Harmonica	78 Whistle	86 Fifths Lead	94 Halo Pad
7 Clavinet	15 Dulcimer	23 Tango Accordion	79 Ocarina	87 Bass Lead	95 Sweep Pad
Guitar Timbres:	**Bass Timbres:**	**String Timbres:**	**Synth Effects:**	**Ethnic Timbres:**	**Sound Effects:**
24 Acoustic Nylon Guitar	32 Acoustic Bass	40 Violin	96 Rain Effect	104 Sitar	112 Tinkle Bell
25 Acoustic Steel Guitar	33 Fingered Electric Bass	41 Viola	97 Soundtrack Effect	105 Banjo	113 Agogo
26 Electric Jazz Guitar	34 Plucked Electric Bass	42 Cello	98 Crystal Effect	106 Shamisen	114 Steel Drums
27 Electric Clean Guitar	35 Fretless Bass	43 Contrabass	99 Atmosphere Effect	107 Koto	115 Woodblock
28 Electric Muted Guitar	36 Slap Bass 1	44 Tremolo Strings	100 Brightness Effect	108 Kalimba	116 Taiko Drum
29 Overdriven Guitar	37 Slap Bass 2	45 Pizzicato Strings	101 Goblins Effect	109 Bagpipe	117 Melodic Tom
30 Distortion Guitar	38 Synth Bass 1	46 Orchestral Harp	102 Echoes Effect	110 Fiddle	118 Synth Drum
31 Guitar Harmonics	39 Synth Bass 2	47 Timpani	103 Sci-Fi Effect	111 Shanai	119 Reverse Cymbal
Ensemble Timbres:	**Brass Timbres:**	**Reed Timbres:**	**Sound Effects:**		
48 String Ensemble 1	56 Trumpet	64 Soprano Sax	120 Guitar Fret Noise	124 Telephone Ring	
49 String Ensemble 2	57 Trombone	65 Alto Sax	121 Breath Noise	125 Helicopter	
50 Synth Strings 1	58 Tuba	66 Tenor Sax	122 Seashore	126 Applause	
51 Synth Strings 2	59 Muted Trumpet	67 Baritone Sax	123 Bird Tweet	127 Gun Shot	
52 Choir "Aah"	60 French Horn	68 Oboe			
53 Choir "Ooh"	61 Brass Section	69 English Horn			
54 Synth Voice	62 Synth Brass 1	70 Bassoon			
55 Orchestral Hit	63 Synth Brass 2	71 Clarinet			

Figure 3.20: List of instruments that can be used to simulate the sound emitted [62].

Mixer: is a Python's 'pygame' library tool for sound processing. This module seamlessly integrates audio features into applications, making it " helpful for controlling playback and loading sound objects" [92]. With 'pygame.mixer', it's possible to effortlessly load and play audio files, layer different sound elements to create dynamic soundscapes, and enhance realism through positional sound.

Image Capture

OpenCV: is a popular open-source computer vision and machine learning software library. "It was created to provide a shared infrastructure for applications for computer vision and to speed up the use of machine perception in consumer products" [87]. OpenCV is written in C++ and has Python bindings, making it accessible to developers working in both languages. With OpenCV, developers can perform image and video capturing, image filtering, feature detection, object recognition, camera calibration, like it is demonstrated in Figure 3.21. It includes a vast collection of functions optimized for real-time computer vision applications. This library is widely used in fields like robotics, augmented reality, facial recognition, object detection, and much more [87]. OpenCV's comprehensive set of features allows developers to manipulate images and videos, extract relevant information, and analyze visual data with ease. Its powerful algorithms can detect objects, track motion, perform facial recognition, and even identify patterns in images.

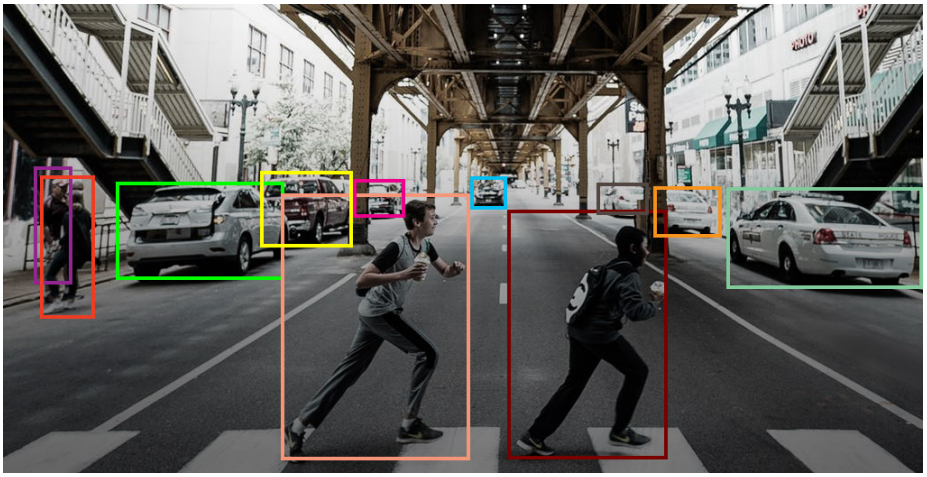
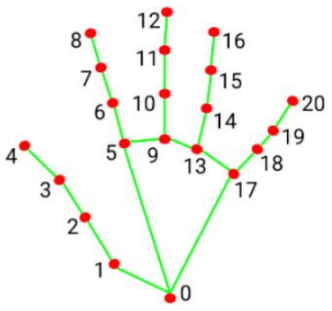


Figure 3.21: Example of how OpenCV can be used for detection of objets or people [94].

Body Detection

MediaPipe: an open-source, cross-platform library developed by Google, empowers developers to create multimedia applications with ease [52]. "When creating Computer Vision models like Face Detection, Pose Estimation, Hair Segmentation, and more, Google's Mediapipe library can save you a lot of time" [52]. Trained on extensive datasets, Mediapipe ensures reliable performance in diverse scenarios, making it an ideal choice for augmented reality, fitness tracking, and more. Employing a two-step detector ML pipeline, the algorithm identifies the person/pose of interest within the frame and subsequently predicts pose landmarks and segmentation masks based on the cropped frame [103]. Looking at Figure 3.22, hands land marks, and Figure 3.23, for pose estimation, it is possible to understand how straightforward it is to identify which body part we want to detect, depending on the purpose of the work that is being developed. Overall, Mediapipe simplifies the implementation of multimedia projects and opens doors to innovative applications.

Hand Land Marks



0. WRIST
1. THUMB_CMC
2. THUMB_MCP
3. THUMB_IP
4. THUMB_TIP
5. INDEX_FINGER_MCP
6. INDEX_FINGER_PIP
7. INDEX_FINGER_DIP
8. INDEX_FINGER_TIP
9. MIDDLE_FINGER_MCP
10. MIDDLE_FINGER_PIP
11. MIDDLE_FINGER_DIP
12. MIDDLE_FINGER_TIP
13. RING_FINGER_MCP
14. RING_FINGER_PIP
15. RING_FINGER_DIP
16. RING_FINGER_TIP
17. PINKY_MCP
18. PINKY_PIP
19. PINKY_DIP
20. PINKY_TIP

Figure 3.22: Hand land markers to identify hands using Mediapipe [36].

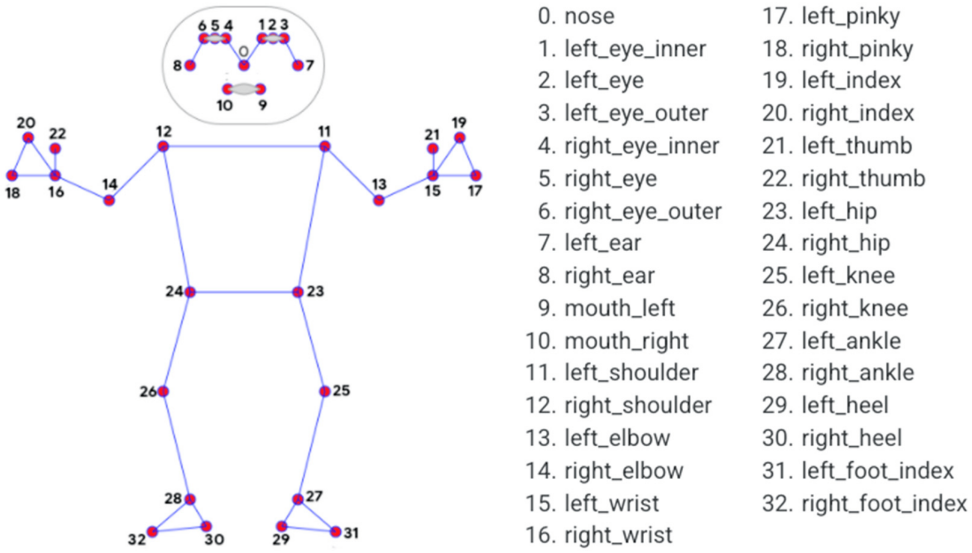


Figure 3.23: Body land markers to identify body parts using Mediapipe [73].

Python's wealth of libraries tailored for sound processing, image capture, body detection, and MIDI processing has greatly influenced the direction of this project. Whether delving into audio processing, image analysis, MIDI generation, or human body tracking, Python's expansive toolkit empowers developers like me to transform innovative ideas into tangible solutions, reflecting the dynamic possibilities that this language offers.

3.2.5 User Interface Design

The user interface (UI) and user experience (UX) design play a pivotal role in shaping the overall gameplay experience of a video game. "User Interface (UI) is an intermediary between users and systems in the form of graphical displays, while user experience (UX) is the experience of users using the user interface" [67]. Each of them play different roles, but end up completing each other as it is represented in Figure 3.24.

Clear and Uncluttered Gameplay Zone

The heart of any game is its gameplay zone, where players interact with characters, objects, and obstacles. "Display clutter is usually associated with negative effects that the amount and arrangement of information can have on user performance" [64]. A clear and uncluttered gameplay zone allows players to focus on the core gameplay mechanics and make informed decisions without distractions.

Consistent Visual Style

Creating a consistent visual style that aligns with the game's theme and genre is essential for fostering an immersive experience. "By creating a consistent visual language and interactions across the product, designers can reduce cognitive load, increase efficiency, build trust, and support scalability" [9]. A consistent visual style establishes a strong identity for the game and enhances players' sense of immersion.

Intuitive Controls

Intuitive and well-placed controls are important for smooth and enjoyable gameplay, meaning "whether they make sense, are easily mastered, and do not interfere with once sense of being in the game" [76]. Ensuring that players can control the game comfortably and intuitively enhances their overall gameplay experience.

Informative Heads-Up Display (HUD)

The HUD provides essential information to players without overwhelming the gameplay. "The HUD provides the information that is simultaneously used to show the main character's health, items, and an indication of game progression e.g. score or level" [39]. The use of icons and symbols can convey information efficiently, minimizing the need for text-heavy explanations.

Effective Feedback and Animation

"Animations are often helpful as a form of noticeable feedback that an action has been recognized by the system" [91]. Well-designed animations enhance the overall gameplay experience by making interactions and outcomes more engaging and satisfying.

Guided Learning and Tutorials

"Effective tutorials help players understand particular game mechanics or teach them to trigger certain behaviour in the game world" [15]. Visual cues, interactive prompts, and hands-on tutorials contribute to a seamless learning curve and empower players to explore the game confidently.

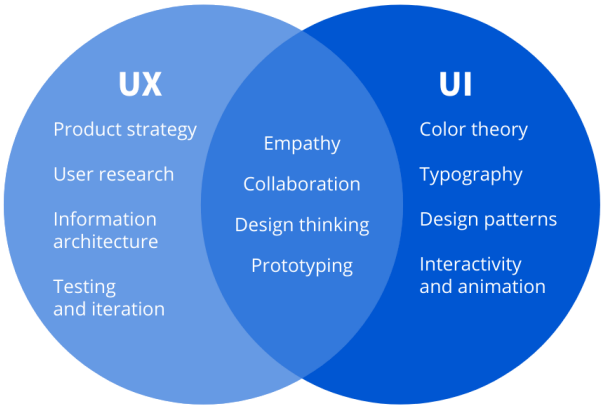


Figure 3.24: UI and UX diagram representation [93].

In conclusion, the UI and UX design have a significant impact on the gameplay experience, making them essential considerations for game developers. By implementing thoughtful and effective UI design principles, game developers can create an immersive and engaging gameplay experience that captivates players and contributes to the overall success of the game.

Chapter 4

Development

4.1 Avatar Creation with Blender

In the development of the app, one of the most significant challenges was creating a 3D avatar that would effectively engage and assist individuals with autism throughout the app's interactive games.

The first step in creating the avatar was designing its 3D shape, which was developed combining artistic creativity with technical skills. This part of the project started by creating a mesh with a simple robot theme, focusing on robot-like features. Blender's extensive range of modeling tools that enabled the creation from scratch of the avatar's facial features, body proportions, and other details with precision, ensuring the creation of a visually appealing and relatable character.

The head was the first thing to be created, followed by the neck and torso, which can be seen in Figure 4.1.

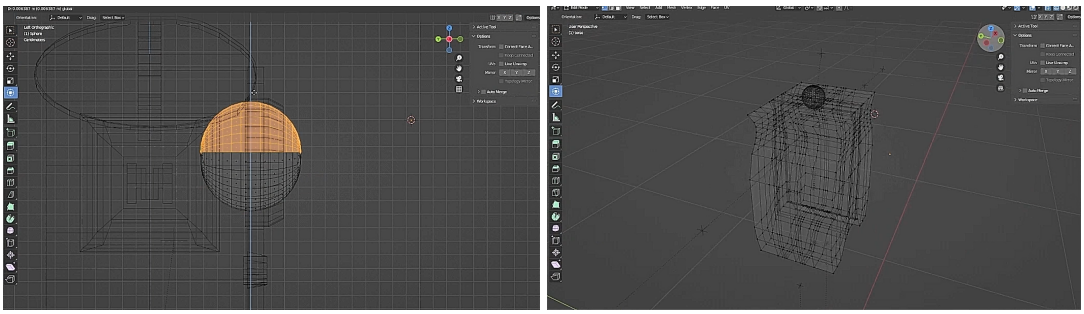


Figure 4.1: Left: Process of creating the head of the avatar. Right: Process of creating the torso of the avatar.

The next step was to create the legs, feet, arms and the hands, as in Figure 4.2. The hands were prepared to be used in case it was necessary to animate the avatar grabbing something, which ended up not being the case.

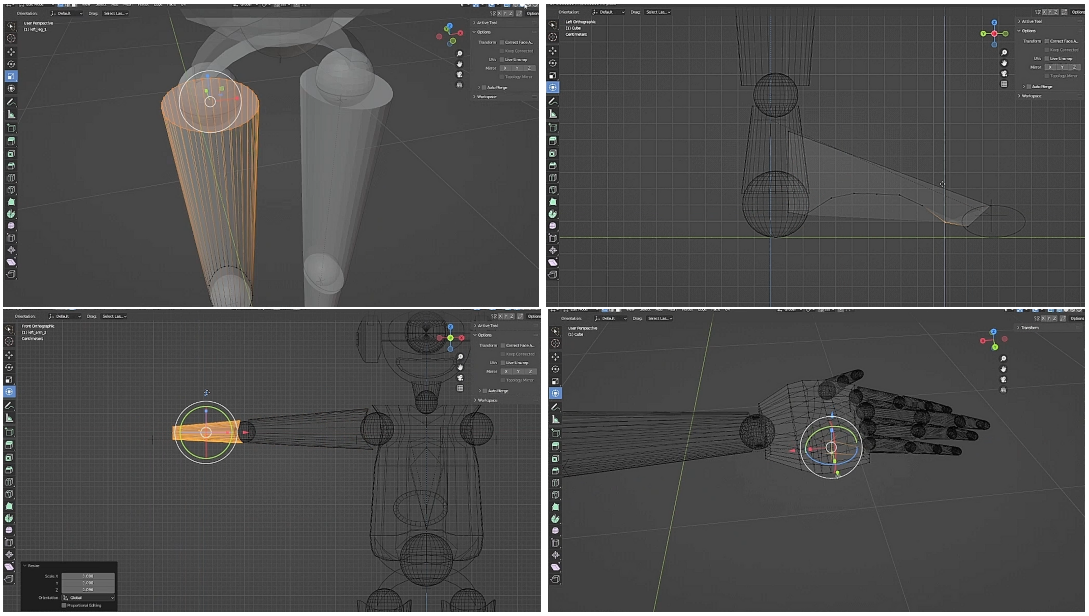


Figure 4.2: Left Top: Process of creating the legs of the avatar. Right Top: Process of creating the feet of the avatar. Left Bottom: Process of creating the arms of the avatar. Right Bottom: Process of creating the hands of the avatar.

To finalize the design of the avatar, the second part was dedicated to the process of texturing and painting it. This stage involved the careful application of textures, colors, light, and materials to the 3D model, where the process can be seen in Figure 4.3 and the final result in Figure 4.4.

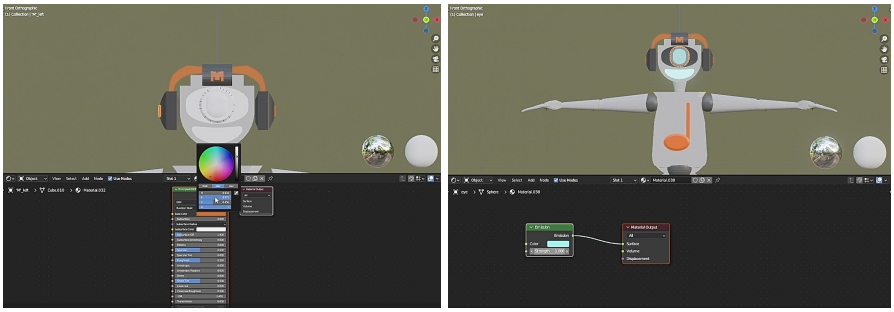


Figure 4.3: Left: Process of painting and texturing the avatar. Right: Process of applying light to some of the avatar's body parts.

Throughout the avatar creation process, it was maintained a user-centric approach, considering the specific needs and preferences of individuals with autism. The avatar's design was carefully tailored to be approachable and non-intimidating, body language that conveyed empathy and support. Blender's real-time rendering capabilities enabled the preview of the avatar's appearance and movements throughout the development, allowing for continuous refinement to achieve the desired user experience.

4.2 Avatar Rigging

In this phase, it was constructed a humanoid armature that acts as a framework for the avatar. The armature consists of interconnected bones, mirroring the structure of a human skeleton. These bones serve as control points, enabling the articulation and manipulation of the avatar's movements with precision. To ensure a lifelike experience, the bones were strategically placed at key joints, such as the shoulders, elbows, hips, knees, and other parts as well, as it can be seen on the right of Figure 4.4.

Figure 4.4: Left: Final result of the 3D avatar created from scratch. Right: Armature associated with the final result of the 3D avatar.

When integrating the armature with the 3D mesh, some challenges related to the association of the armature with the mesh can appear, especially when dealing with a complex model created from scratch, as is the case with this app's avatar. The high number of vertices in the mesh makes it challenging to seamlessly associate the armature with the avatar. To overcome this, various techniques were used, including vertex reduction and optimization, to simplify the mesh's complexity without compromising its visual quality.

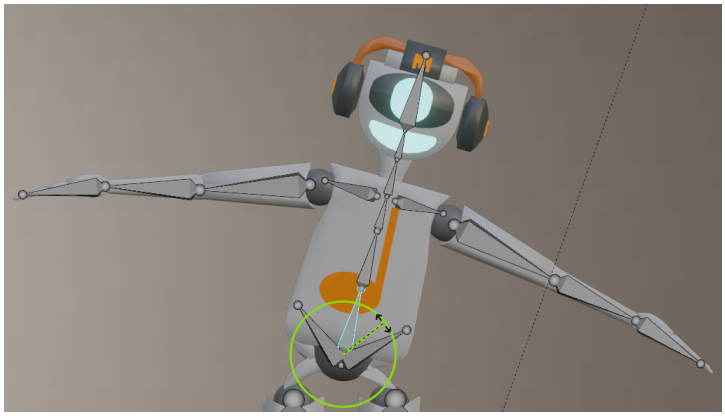


Figure 4.5: Result of the rigging process with rigify of the 3D avatar in Blender.

Once the rigging is complete, the avatar becomes an animated entity capable of re-

sponding to user input and interactions within the app. During the development of the avatar rigging process, the rigging was continually fine-tune to ensure that the avatar's movements align seamlessly with its virtual skeleton, avoiding any unnatural deformations or unintended glitches, with the result in Figure 4.5.

4.3 Motion Capture Calibration and Animation

Before starting the creation of the animations, there was a calibration phase, which is a crucial step in the motion capture process, where precision and accuracy were paramount to ensure reliable and realistic motion data. To achieve this, the motion capture system utilized a wand and a triangle for calibration, the same that are in Figure 4.6.

Figure 4.6: Left: Wand. Right: Triangle. [14]

The wand, a handheld device equipped with reflective markers, played a central role in the calibration process. The reflective markers on the wand served as reference points that the motion capture cameras could detect and track. During calibration, the wand was used to establish the spatial relationship between the motion capture cameras and the area where the performer's movements would be captured. The motion capture system required a clear and unobstructed view of the reflective markers on the wand from multiple camera perspectives. By moving the wand within the motion capture volume and allowing the cameras to detect its position and orientation, the system could determine the 3D space and camera perspectives, thus calibrating the motion capture environment. This process was repeated from various angles and positions to ensure comprehensive coverage of the calibration area, which enabled to obtain an exceptional result on the wand calibration as demonstrated on Figure 4.7.

The triangle was another essential component used during calibration. This triangular frame was equipped with reflective markers at known positions, allowing the motion capture system to precisely calculate the dimensions and angles of the triangle. By analyzing how the triangle's markers were detected by the cameras from different viewpoints, the system could fine-tune the camera positions and further optimize the calibration process.

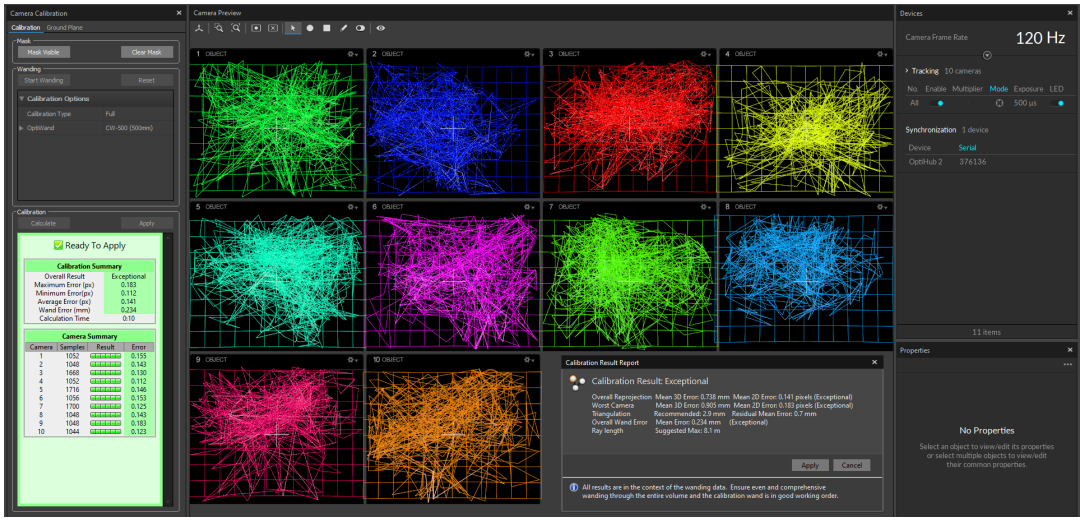


Figure 4.7: Wand calibration result.

By establishing the spatial relationship between the ten motion capture cameras and the performer's movements, the calibration ensured the accuracy and precision necessary to capture realistic and lifelike motions.

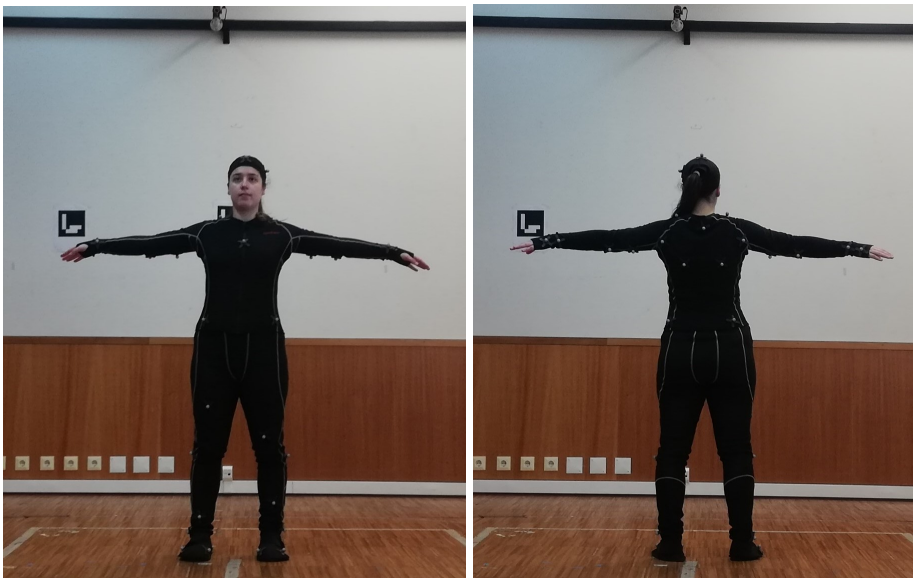


Figure 4.8: Performer equipped with the suit and the 37 markers. Left: front view. Right: back view.

After the calibration of the cameras, the creation of the animations was executed while wearing a specially designed suit with 37 reflective markers, as in Figure 4.8. These markers served as reference points for tracking the performer's movements. After calibrating the skeleton in T-pose, where the result is in Figure 4.9, the performer enacted various actions and gestures, and the ten motion capture cameras recorded the precise position and orientation of each marker in three-dimensional space.

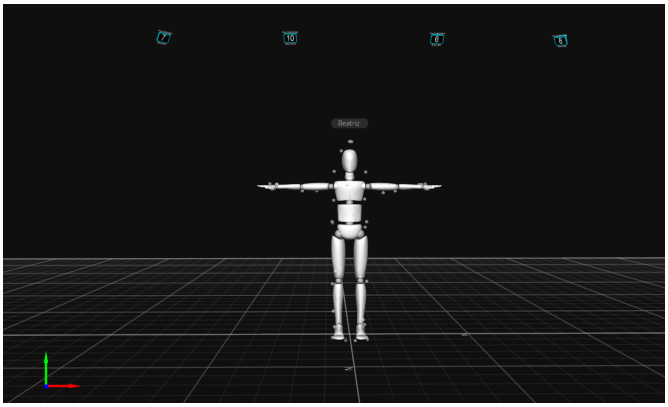


Figure 4.9: Result of the skeleton formed from the 37 markers that were detected by the 10 cameras.

Once the motion data was captured, it underwent extensive processing to ensure accuracy and consistency. The data was transformed into a digital format that could be interpreted by the 3D software, Blender, used in our app's development. Advanced data refinement techniques were applied to eliminate any noise or imperfections, resulting in smooth and natural animations.

4.4 Animation Integration in Blender

The processed motion data was mapped to the virtual 3D avatar's armature within Blender. By associating the motion capture data with the avatar's skeletal structure, using the add-on "Rokoko" that automatically creates a list of bones that match each skeleton to each other, the performer's movements were seamlessly mirrored onto the digital character, as in Figure 4.10.

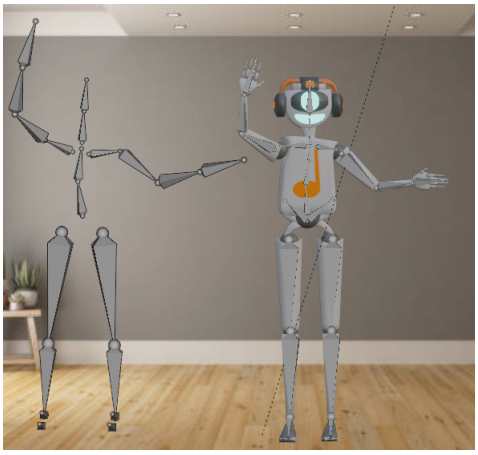


Figure 4.10: Resulted association of the animation created with motion capture and the 3D avatar created in Blender.

One significant advantage of motion capture was its time efficiency. By directly capturing human movements, the development of this part of the project was spared the

laborious task of hand-animating every frame. This saved valuable time and effort, having enough time to focus on fine-tuning and perfecting the motions for optimal results. However, the use of motion capture did present some challenges. Ensuring accurate alignment of the motion data with the avatar's skeleton required careful calibration and data processing.

4.5 Application

As mentioned before this app features four interactive games, each tailored to address specific difficulties that individuals with autism may encounter. From memory and visual perception to attention and coordination, this interactive games aim to cater to a wide range of abilities, providing an inclusive experience for all users. As it was explained in the development tools section, using python proved to be very beneficial, for its many libraries were very useful on the development of the interactive system, especially for the implementation of the games.

Although each game is different, in terms of how the individual is supposed to play it, they all have many things in common when it comes to game logic and the libraries that were used to develop them. For example, Pygame was used for almost everything, including drawing rectangles for the layouts, checking if the sprites collide with the respective body parts - that are being detected with Mediapipe -, and for loading the background music, feedback sounds and the voice lines from the avatar with mixer. OpenCV was used to capture the image, while mediapipe detects the body part.

4.5.1 Gameplay layout

Different gameplay modes often require distinct layout approaches to ensure players can seamlessly interact with the game mechanics and access relevant information. In the development of the games for this project, two specific layout designs were strategically chosen to accommodate the unique requirements of gameplay involving rounds and gameplay with a timer.

Layout for Games with Rounds

For games structured in rounds, the layout aims to provide players with a holistic view of their progress, scores, and available resources. The layout comprises a central gameplay zone flanked by strategic UI elements. On the left side, a column hosts essential components such as a back button, an avatar image (representative and non-moving), the logos of associated labs and the university, and the app's title ("Muse4U"). This column serves as a consistent point of reference and navigation for players. The avatar's voice feedback enhances the user experience, fostering a sense of positive interaction.

Within the gameplay zone, additional elements are thoughtfully placed to assist players. A box in the top-left corner tracks the progress of rounds, enabling players to keep track of their advancement. Meanwhile, a box in the top-right corner dynamically displays the player's current score, providing real-time feedback on their performance. Lastly, a box in the bottom-right corner monitors the player's available lives, ensuring

that players are aware of their resources. All of this description is exemplified in Figure 4.11.

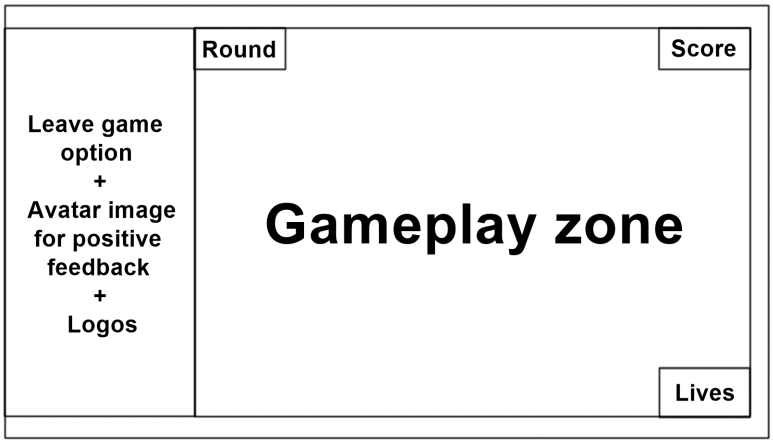


Figure 4.11: Round game layout.

Layout for Games with Timer

Games centered around a timer call for a different layout configuration to ensure that players' focus remains on the gameplay and the time remaining. The layout retains the left-side column from the previous design, housing essential UI elements such as the back button, avatar image, logos, and app title.

However, the gameplay zone itself is streamlined to prioritize the gameplay experience. Elements not directly related to gameplay are minimized in this mode to prevent distractions. Information about scores and the timer is efficiently displayed in a smaller column on the right side of the layout. By placing these elements adjacent to the gameplay zone, players can easily gauge their progress and remaining time without diverting their attention. All of this description is exemplified in Figure 4.12.

Figure 4.12: Timer game layout.

In both layout designs, the strategic placement of UI elements takes into account players' intuitive interaction patterns. Essential information is readily available without obstruct-

ing the core gameplay experience.

Because pygame also has a function that reads the screen size, the layout of each game, be its sprites or the rectangles that are drawn, have their positions in relation to the size of the screen, meaning that they are not fixed numbers. Which is a great advantage if we want to display the interactive system in different screens.

4.5.2 Sprites, Music and Sounds

All the sprites used in this interactive system, except for the "hand" sprite that is used to navigate in the menus and is also a sprite included in the first game, were drawn by me using the application SketchBook from Autodesk. That software was also helpful in the creation of the gifs that are displayed on the information menus, to create the images of the sprites of the game itself accordingly with the movements of the avatar - created in motion capture. This can be seen in three stages, where: Appendix B displays the avatar animation alone; Appendix C displays the sprites animation alone; and Appendix D displays them together, as they are seen in the information menus.

The background music was not created by me, it was chosen from a Youtube channel called 'Poco Cute' that creates relaxing, simple and enjoyable music. Same goes for the feedback sounds, that were obtained in a site called 'mixkit' where it is possible to download a large variety of sound effects.

4.5.3 Game Logic

In the first game, mediapipe only detects their hands, more specifically their index finger of both hands, which have the sprites from Figure 4.13 associated. While the game is showing the sequence of pair of images that the individual needs to replicate, the sprites of the hands disappear to let them know that is not possible to select any image of the game while the sequence is being displayed.

While the images are being displayed, MIDI is being used to play the sounds that correspond to each of the pair of images - orange pair is C ('Dó'); blue pair is D ('Ré); green pair is E; purple pair is F. Each time the sequence is wrong, the number of lives goes down by '1', and the score goes down by '25'. Each time the sequence is right, the score goes up by '50'. This is executed in a function that verifies if the user has selected the same number of pair of images as the sequence that was displayed. There is no background music, but there's feedback sound and also the avatar voice lines, that are played using mixer.

As there needs to be a verification process to check if the sequence that the user selected corresponds to the sequence given by the game, two tables are used. The table for the random sequence is filled during the game, with the correspondent string that represents each pair of images. So, for example, in the first round that table only has one string, in the second round it has two strings, in the third round has three strings, and so on. A second table is used to store what the user selected in that round and then compare it to the base sequence, to then be deleted and refilled again in the next round of selection.

Figure 4.13: Sprites used to associate with the hands detected on the first game.

In the second game, mediapipe is used to detect both elbows and feet of the individual. A separated function was created to randomly set the speed and location of the sprites that "fall" from the screen - they start at the top and end at the bottom of the screen. Depending on how many times the sprites have "fallen", the speed goes up, but it is still random.

Every time an elbow touches the leaf that is not supposed to be touched, it deducts 5 points, and each time a foot touches that same leaf, it deducts 2 points, as it is more difficult to control the feet when the sprites are arriving at the bottom. The time bonus, which also has a random speed, can be caught with the elbows or feet and it adds ten seconds to the timer. Every time that there's a collide, the mixer, that is being used to play the background music, is used to play the feedback sounds and the avatar voice lines.

Both the leafs and the bonus are inserted in a table and, when there's a collide or when they reach the bottom, they are removed from that same table. It only creates a new table, with a random combination of leafs and bonus, when the previous table is empty.

As for the third game, mediapipe is used to detect both sides of the hips and both knees. With the coordinates of each side of the hips, it is possible to find the middle point in 'x', and then place the sprite that we want, in this case is the bee, in the middle of the torso, that being the 'y' direction. Instead of having the flowers and the wasps coming in top-to-bottom direction as in the second game, they come from left-to-right and right-to-left, using the same separated function to control their speed and random location on the screen as they appear.

When the bee touches a wasp, the number of lives goes down by '1', and the score goes down by '15'. However, when the bee touches the flowers the score goes up by '15' and when the shield is used to touch the wasps the score goes up by '5'. As described for the second game, the background music, feedback sounds and avatar voice lines are all being played with mixer.

As explained for the second game, the flowers and the wasps are also inserted in a table, and it only creates a new table when the previous one is empty. For example, if the sprites that are going to appear are the flowers from the left-to-right, then it fills a table with three flowers and it only creates a new one when the bee touches all the flowers or if they all reach the right side of the screen.

Finally, for the fourth game, mediapipe is used to detect only the hands, more specifically the index of both hands as in the first game. The associated hand sprites are in Figure 3.8, where the Christmas candy (top left) is for the right hand and the tool (top right) is for the left hand.

When the snowflake appears above one of the lights, and at the same time a pair of lights goes off, there is a timer that becomes shorter as the number of rounds increases. If

the timer ends and both or one of the actions is not completed, the number of lives goes down by '1' and the score goes down by '10'. When both actions are completed within the time, the score goes up by '25'. There is background music, and feedback sounds, and the avatar voice lines that are also played by mixer.

In this case, the sprites are not directly inserted in a table, but their 'x' and 'y' coordinates are. The sprites for the completion of the actions are chosen randomly, so it can happen that the same pair of lights that went out also has a snowflake to take care of. To simulate the pair of lights that went out, the alpha value of the images is reduced, and to simulate the inverse (the lights lighting up again) the alpha value is increased.

The variables used to continually calculate the number of lives and scores of the games are local variables that have a reset every time the user exits the game, be it by finishing it or going back to the information menu. The same happens to the timer, for the second game, and also the timer that is counting the time played on each game.

4.5.4 Information Menu Logic

The text that is displayed in the information menus is created using pygame, and then put in specific locations so it is organized in a certain way for every one of the information menus. The avatar appears both in the text, as a still image that is connected with the mixer that gives plays the explanation of how to play the game, and in the visual display as a gif. For the voice lines of the avatar, it was used a converter of text-to-voice, where it was possible to choose the language and the tone of the voice to be used. The images of the gif are overlapping, that meaning that the gif of the avatar alone (that was created using motion capture for the movements) is below the gif that displays the sprites animated to simulate a gameplay. There is a separated function to 'play' the gifs. In that function, the number of images of the sequence, avatar and sprites, is defined, by knowing the correspondent information menu, and they are both displayed at the same time, to simulate a gameplay. It is also prepared to continuously repeat the sequence of images, so the gif is always playing.

4.5.5 Leaderboard Logic

The leaderboards are created automatically, if there is none, and it consists of an excel file for each game where it is possible to store the name, score and time played. On the application it only shows the first eight indexes, from 0 to 7, and can be found at the end of each game or in a menu that is accessible from the main menu. If the user wants to add their score and the excel file already exists, then the new input - name, score and time played - will be added to the existing list only if there is no name with the same characters and if the score is higher than the last score of the list. The name is added as a string, the score and time played are added as integers.

Chapter 5

Validation and Data Collection

5.1 Interactive System Validation

The interactive system underwent a rigorous validation process, aimed at ensuring its effectiveness and suitability for individuals with and without autism. Early in the development phase, a preliminary demo was presented to a group of individuals on the autism spectrum. This initial feedback provided invaluable insights into the system's strengths and areas requiring improvement, helping to shape the subsequent development process. Based on the feedback received, a series of games were meticulously designed, each one targeting specific cognitive and motor skills to address the diverse range of challenges experienced by individuals with autism, as mentioned in the development chapter.

Throughout the iterative development process, the system's games were continually refined and enhanced, always with the users' needs and preferences at the forefront. The incorporation of vibrant visuals, engaging sounds, and intuitive gameplay mechanics sought to foster an enjoyable and immersive experience for all users.

5.2 Data Collection

The quantitative data collection and analysis process played a pivotal role in evaluating the effectiveness and user experience of the developed interactive system. This component aimed to provide objective insights into various aspects of the system's performance and user engagement. The study was conducted in two key phases: testing with individuals with autism and/or characteristics of autism, and a control group of individuals without autism and without characteristics of autism.

Accessing a diverse group of testers, including individuals with autism and those exhibiting autistic characteristics, was a crucial phase in this research project. This was made possible through the generous support and collaborative efforts of the CRIF institution, with special thanks to Dr. Sandra Reis.

Dr. Sandra Reis, the most important connection between the project and the CRIF institution, played a pivotal role in facilitating the necessary connections and arrangements. Her commitment to advancing research in the field of autism and her deep understanding of the importance of this work were evident throughout our collaboration. Dr. Sandra

Reis not only arranged the initial meeting, where it was possible to demonstrate and introduce the project and the application, but also arranged a date for me to obtain the important results that were still needed to complete this project. Furthermore, with Dr. Sandra Reis' guidance and coordination, I had the privilege of collaborating with Dr. Catarina Santos, a skilled psychologist. Dr. Catarina Santos' expertise was instrumental in conducting the tests with the participants. Her insights into the unique challenges and characteristics of autism greatly enriched the data collection process, ensuring that the project maintained a high standard of quality and professionalism.

The CRIF institution's commitment to promoting research in the field of autism and the invaluable support of Dr. Sandra Reis and Dr. Catarina Santos were essential in gaining access to the testers and conducting meaningful tests. Their dedication to this project has been instrumental in advancing our understanding of autism and its interaction with interactive systems.

This quantitative component involved administering the User Experience Questionnaire (UEQ) to participants after they interacted with the app. The UEQ is a standardized tool designed to assess the user experience of interactive products, systems, and applications, and can be seen in more detail on the next subsection. The questionnaire provided valuable data on participants' subjective experiences with the app, allowing for a comprehensive evaluation of its usability and overall user experience.

In regards to ethical considerations, the research adhered to strict ethical guidelines, obtaining informed consent from all participants and their guardians before the testing sessions. Privacy and anonymity were maintained throughout the analysis and reporting of the data.

5.3 User Experience Questionnaire (UEQ)

"The User Experience Questionnaire (UEQ) is a framework that can assist researchers in processing survey data with an easy, valid, and reliable application" [25]. In the context of this research, the UEQ was chosen as a key instrument to evaluate the user experience of the app developed for individuals with autism and/or with characteristics of autism, as well as the control group that includes people without autism or characteristics of autism. This section provides an in-depth overview of the UEQ, including its purpose, the scales it encompasses, and its administration.

5.3.1 Purpose of the UEQ

The UEQ's primary goal is to quantitatively assess different facets of the user experience, offering valuable insights into users' emotional responses, including feelings of pleasure, disappointment, and fear when using the product [68]. By utilizing the UEQ, researchers can systematically evaluate the effectiveness, usability, and overall satisfaction of an application, enabling a deeper understanding of how users interact with the product and how it aligns with their needs and expectations.

5.3.2 Scales of the UEQ

The idea is to merge pragmatic elements such as effectiveness and efficiency with hedonic aspects encompassing aesthetics, usability convenience, and appeal. That being said, the UEQ consists of a total of 26 items, as it is displayed in Appendix F, strategically grouped into six key scales, that can be represented in the structure displayed on Figure 5.1, to comprehensively represent different aspects of the user experience:

1. Attractiveness: This scale assesses the aesthetic appeal, visual design, and overall impression of the app. It delves into the app's appeal and its ability to evoke positive emotions and engagement from users.

2. Perspicuity: The perspicuity scale focuses on the app's clarity and ease of understanding. It evaluates how well users can navigate the interface, comprehend the app's functionalities, and accomplish tasks efficiently.

3. Efficiency: This scale measures the app's efficiency in supporting users to achieve their goals quickly and with minimal effort. It reflects the effectiveness of the app in fulfilling its intended purpose.

4. Dependability: The dependability scale gauges the app's reliability and stability. It aims to determine the level of trust users place in the app's consistent performance and responsiveness.

5. Stimulation: The stimulation scale quantifies the level of engagement, excitement, and interest evoked by the app. It assesses the app's ability to captivate users and sustain their attention.

6. Novelty: This scale assesses the perceived innovation and novelty of the app. It considers whether the app introduces fresh ideas or features that distinguish it from other existing solutions.

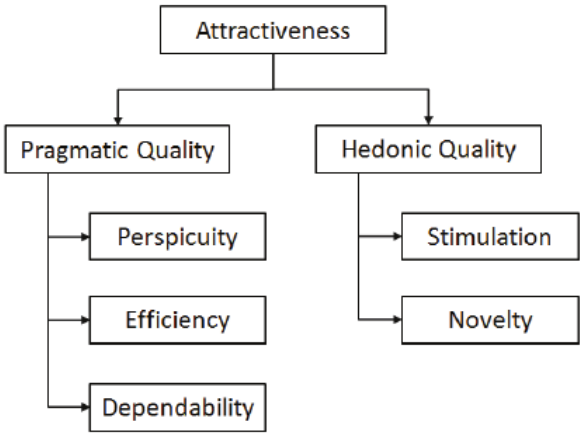


Figure 5.1: Scale structure of the UEQ [75].

5.3.3 Administration of the UEQ

Following the participants' interaction with the app, they were asked to complete the UEQ, providing their responses based on their experience. Due to the specific cognitive challenges experienced by individuals with autism and/or characteristics of autism, the questionnaire was answered by Dr. Catarina Santos. Since Dr. Catarina Santos accompanied all the tests that were realized in the CRIF institution, it was possible to answer the questionnaire for all of them, as a collective answer for all of the individuals.

The questionnaire comprises a bipolar 7-point scale for each item, ranging from "Strongly Positive" to "Strongly Negative." This response format allows for a nuanced assessment of participants' attitudes and feelings towards specific aspects of the app's user experience. For the analyses of the results, UEQ already has an excel sheet prepared to simply input the results obtained from the participants, and then generate all the graphs and values that are needed to analyse the final results. As it can be seen on the next chapter, the results from the group without autism or characteristics of autism, and the results from the group with autism and/or characteristics of autism are analysed separately. This approach makes sense because they are a very different group of individuals and, for this project, the target group ends up always being the one were the results are more important, either for the improvement of this work or for eventual future work in this field.

5.4 Results and Discussion

The following section presents the results of the User Experience Questionnaire (UEQ) analysis, focusing on individuals without autism or characteristics of autism and then individuals with autism and/or characteristics of autism. The graphical representations provide a clear visual overview of participants' perceptions and responses, shedding light on various dimensions of the app's design and functionality. These results contribute to a comprehensive understanding of the app's effectiveness in engaging and supporting users without autism, setting the stage for a comparative examination with the responses obtained from the tests with the individuals with autism and/or characteristics of autism in the subsequent section.

Each group tested the application, where the control group tested all the games, and the other group only tested specific games depending on the difficulties that they have. Both groups were asked to test the games in 'train' mode so it wouldn't take too much time. However, some of the participants later chose to try the 'game' mode and had the opportunity to experience some of the games more immersively.

5.4.1 Group without autism or characteristics of autism

The evaluation of the interactive app and games extended to a diverse group of 15 participants without autism or characteristics of autism, with ages spanning from 8 to 48 years. This inclusive age range ensured a comprehensive analysis of the app's impact across various life stages. Additionally, the participants in this group represented a mix of Portuguese and non-Portuguese individuals, enriching the study's diversity. It is worth

noting that the participants' diverse backgrounds and age ranges contribute to a well-rounded assessment of the app's user experience. Their feedback, combined with the collected quantitative data, offers a comprehensive view of the app's usability and effectiveness for individuals without autism or characteristics of autism.

In the following Figure 5.2, the mean values per item on the UEQ scales are presented in form of graph, offering an overview of participants' evaluations in different dimensions. Each scale corresponds to a unique facet of the user experience, providing insights into the app's strengths and areas for improvement. The graph not only quantifies participants' responses but also offers a nuanced understanding of their qualitative feedback.

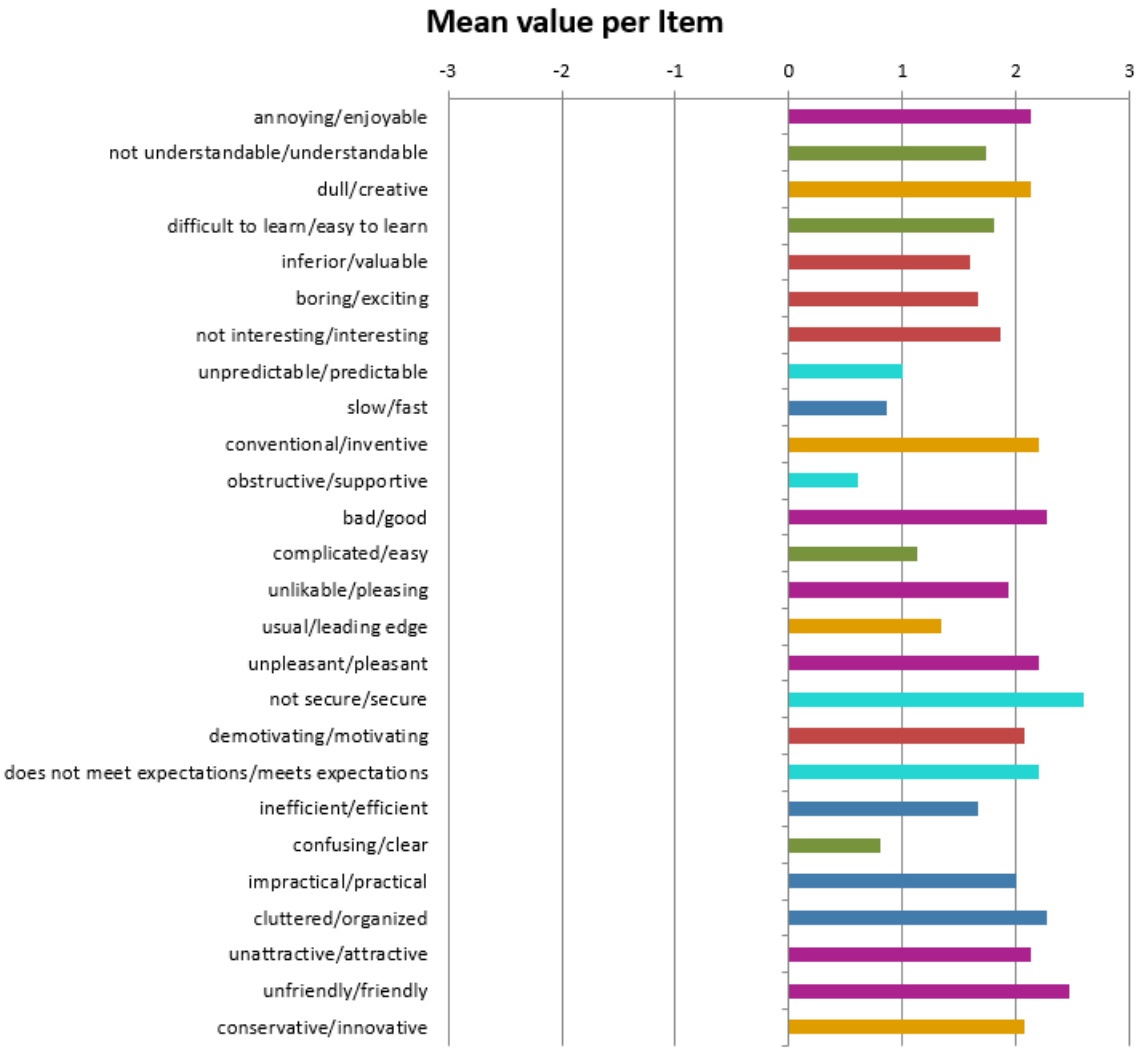


Figure 5.2: Mean value per item, from the group without autism or characteristics of autism.

The upcoming two figures, Figure 5.3 and Figure 5.4, present the outcomes of the questionnaire with a focus on the UEQ scales. These graphics seamlessly consolidate the responses from Figure 5.2, offering a combination that solidifies into the final assessment across these six scales.

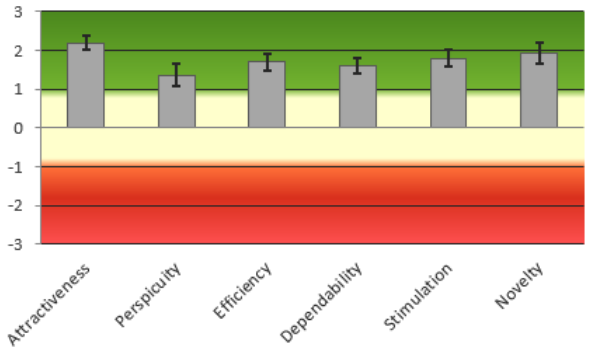


Figure 5.3: Mean of each scale, from the group without autism or characteristics of autism.

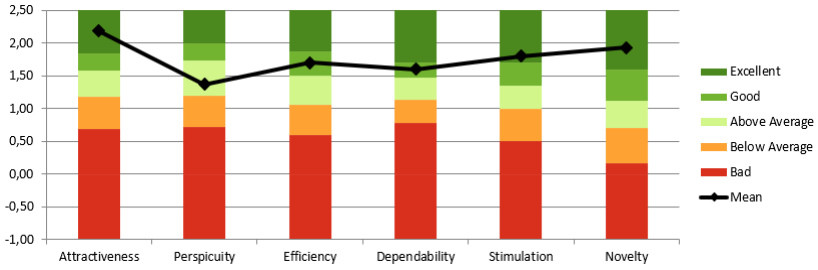


Figure 5.4: Benchmark, from the group without autism or characteristics of autism.

The final graph, displayed in Figure 5.5, visually portrays the distribution of participants' choices among different response options for each individual question, presented as a percentage.

Individual Question Analysis

Taking a closer look at the average ratings for each item, in Figure 5.2 and Figure 5.5, it's possible to see a distinct pattern in participants' perceptions. It's also evident that the interactive system received positive feedback across various aspects, which indicates that both the app and its games were well-received and effectively captured users' interest. Notably, participants enjoyed using the app, found it easy to understand, and appreciated its creative elements. This suggests that the app offered an engaging and user-friendly experience.

Scale-Based Analysis

Looking at the analysis by scale, it's possible to observe consistent trends that align with the broader picture. The scale of "Attractiveness" received a mean value of 2.189, suggesting that participants found the app visually appealing and engaging. The scale of "Perspicuity" ended up with a mean value of 1.367, indicating that the app's interface and functionalities were clear and easy to understand. The scale of "Efficiency" obtained a mean value of 1.700, reflecting participants' perceptions that the app's interactions were well-organized and efficient.

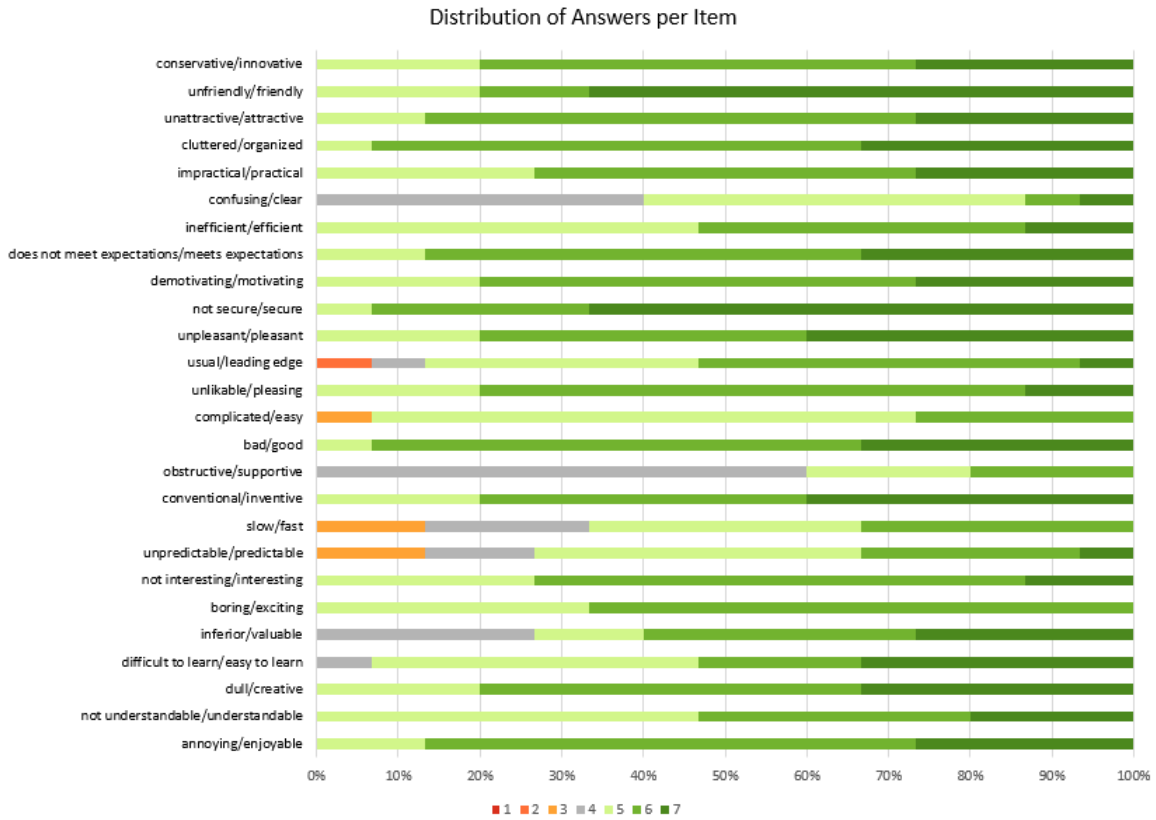


Figure 5.5: Distribution of the answers, from the group without autism or characteristics of autism.

Moreover, the "Dependability" scale yielded a mean value of 1.600, indicating that participants trusted the app's consistent performance and stability. The scale of "Stimulation" received a mean value of 1.800, implying that the app succeeded in engaging and stimulating users emotionally. Lastly, the "Novelty" scale got a mean value of 1.933, highlighting that participants appreciated the app's innovative and creative elements.

5.4.2 Group with autism and/or characteristics of autism

The assessment of the interactive app and games extended to a unique group of testers, consisting of one individual diagnosed with autism and three others who exhibited characteristics associated with autism. The age range within this group was between 35 to 49 years, encompassing a variety of life stages and experiences. All participants had verbal communication abilities, but they required varying degrees of support and assistance in their daily lives, indicating that they were not fully autonomous. Each tester had distinct characteristics, with two displaying more developed traits related to autism than the other two. Due to their individual profiles and preferences, not all games were tested. The individuals that had more limitations and challenges preferred to play the games that use the body movements (the second and the third game), while the ones that have more capabilities were able to play the memory game, which uses the hands. The fourth game was not tested, as it would be more difficult for these individuals in specific. However, Dr. Catarina said that even the ones that did not play the games where they need to use their

hands, with practice they could eventually learn and be capable of playing those games. It's important to acknowledge that introducing new experiences and interactions can be challenging for individuals accustomed to specific routines and sensory sensitivities.

As mentioned before, Dr. Catarina Santos provided essential guidance, support, and insight throughout the testing procedures. Despite these complexities, their participation, along with Dr. Catarina Santos' guidance, provides valuable insights into the app's usability and effectiveness for individuals on the autism spectrum or with related characteristics. Their diverse backgrounds, age distribution, and varying degrees of autism-related traits contribute to a comprehensive assessment of the app's user experience. In combination with the collected quantitative data, their feedback offers a nuanced perspective on the app's ability to cater to the needs and preferences of individuals with autism or related characteristics.

The first figure, Figure 5.6, displays the mean values per item on the UEQ scales in the form of graph. Knowing that Dr. Catarina Santos answered the questionnaire taking into account all of the participants interactions with the games that each experimented, this first figure basically shows the answers given by Dr. Catarina Santos, which is already the mean value per item.

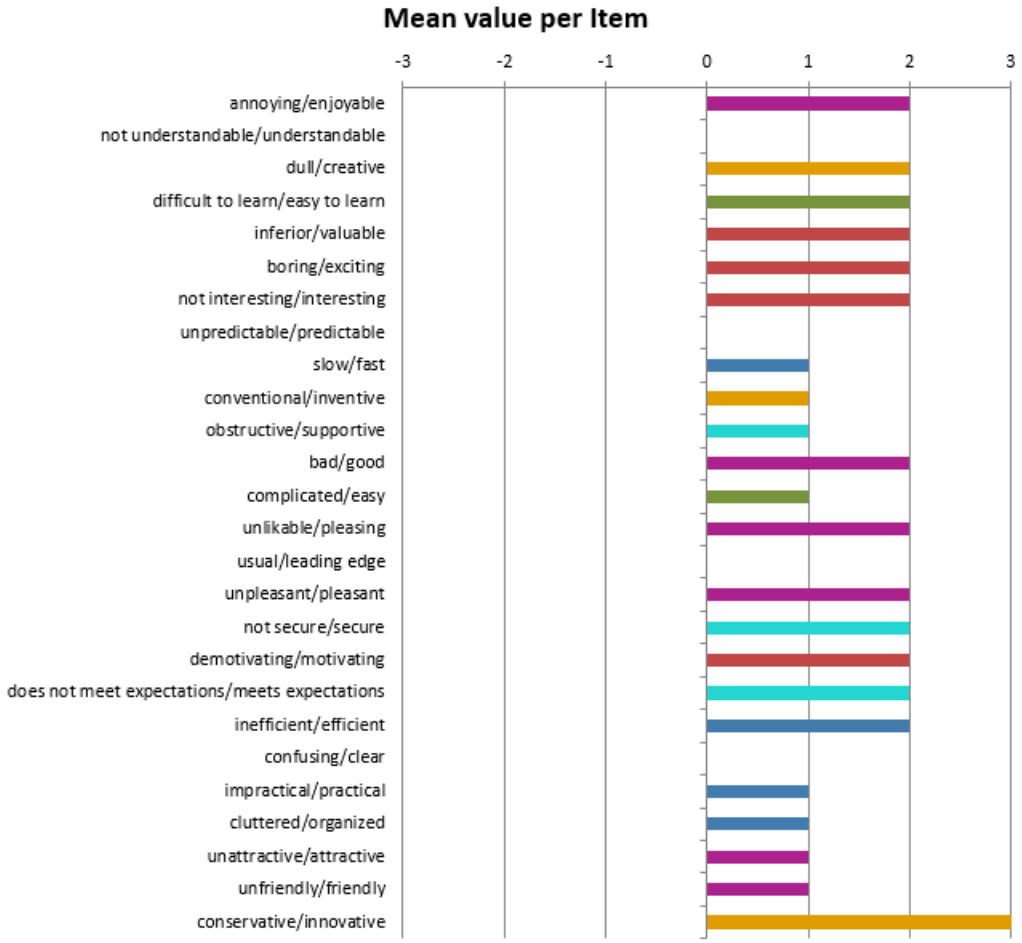


Figure 5.6: Mean value per item, from the group with autism and/or characteristics of autism.

The following two figures, Figure 5.7 and Figure 5.8, as in the previous section results, depict the results of the questionnaire, with a specific emphasis on the UEQ scales. These visual representations integrate the data from Figure 5.2, providing a comprehensive overview that ultimately contributes to the overall evaluation across these six scales.

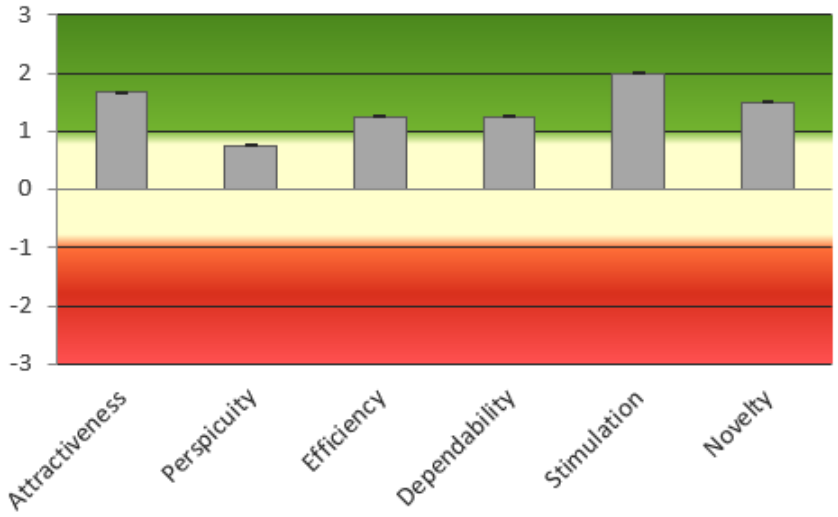


Figure 5.7: Mean of each scale, from the group with autism and/or characteristics of autism.

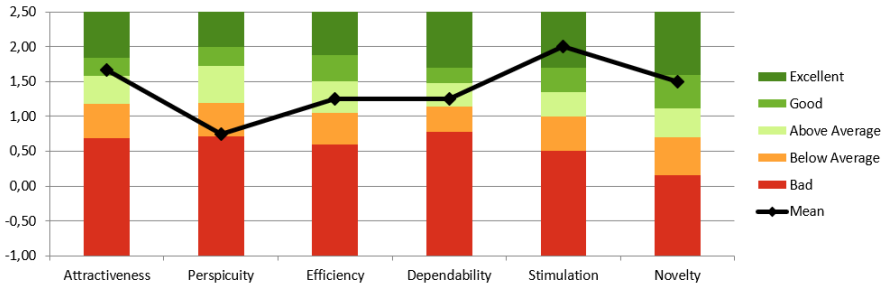


Figure 5.8: Benchmark, from the group with autism and/or characteristics of autism.

Individual Question Analysis

Upon analyzing the answers that Dr. Catarina Santos selected in each item of the questionnaire, it's possible to understand that the experience had a positive impact on each of the participants. Knowing that each participant has different characteristics and limitations, the results presented display a positive evaluation of the system, with place for improvement. Which suggests that the app and the associated games were also well-received and succeeded in engaging users.

Scale-Based Analysis

The app was generally considered highly attractive, earning a mean score of 2. This suggests that participants found its visual elements and design engaging and visually appealing. Regarding perspicuity, the app scored an average of 0.75, implying that there's

room for improvement. However, it also indicates that the app's interface and functionalities were somewhat clear and understandable to participants. In terms of efficiency, the app received an average score of 1.5, indicating that participants found its interactions moderately efficient. This suggests potential for enhancing the organization and efficiency of interactions. Dependability earned an average score of 1.25, suggesting that participants generally trusted the app's performance and stability. However, there may be opportunities for further enhancement in this regard. The app excelled in providing stimulation, receiving a mean score of 2, indicating that participants found the interactive activities engaging and emotionally stimulating. Participants appreciated the app's innovative and creative elements, as indicated by a mean score of 1.5.

In summary, after the realization of the tests, Dr. Catarina Santos reported positive perceptions of the app's attractiveness and stimulation, with room for improvement in terms of perspicuity, efficiency, and dependability. These insights provide valuable guidance for refining the app to better meet the needs and preferences of this user group.

5.4.3 Discussion

The evaluation of the interactive app and games for individuals with autism characteristics yielded valuable insights into usability and user experience. Participants found the app highly attractive and stimulating, indicating its success in engaging users visually and emotionally. However, areas such as perspicuity and dependability could benefit from improvement to ensure a seamless user experience. These findings align with user-centered design principles emphasizing the importance of engaging design for user engagement and satisfaction. Practically, the positive aspects of the app can serve as a foundation for enhancing user engagement, while identified areas for improvement offer guidance for refinement. Limitations include a limited sample size and diverse participant characteristics. Future research should expand the participant pool and incorporate direct user feedback.

After the tests, Dr. Catarina Santos mentioned that depending on the level and characteristics of autism that an individual can have, some of the games were more appropriate for a specific group of individuals, while other games were a bit advanced. Doesn't mean that they couldn't play them, but it would be more challenging to introduce it to them and it would take much more time and patience.

Nonetheless, the participants in the autism and/or autism characteristics group exceeded my expectations. Despite the unique challenges they face, witnessing their engagement and enjoyment while playing the educational and skill-building games was truly remarkable. These games were specifically designed with this target audience in mind, and it was a rewarding experience to see such a positive response from the individuals this project aims to support. Their enthusiastic participation was both inspiring and reassuring.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

In conclusion, this research undertook the ambitious task of creating an interactive application aimed at enhancing motor, visual, and memory skills in individuals with Autism Spectrum Disorder (ASD). The development of this application was grounded in a user-centric approach, drawing inspiration from methodologies spanning motion capture technology, interactive game design, and user experience evaluation. The results achieved through the rigorous design process are encouraging, illuminating the potential of technology to foster skill development and engagement in individuals with ASD or with characteristics of ASD.

The culmination of this project materialized an interactive application whose concept was presented on the ExpAT'23 conference [10] and validated with a group of autistic subjects under the supervision and guidance of a psychologist. The positive feedback received from both groups underscores the application's universal appeal and engaging design. The findings obtained from the User Experience Questionnaire (UEQ) illuminate the application's strengths in terms of user engagement, aesthetics, and usability, thereby validating the attentive design and development efforts.

6.2 Future Work

While the interactive application has demonstrated promising results, there remains a wealth of opportunities for further enhancements and expansions. Beyond the insights garnered from the UEQ analysis, several avenues for future work emerge:

1. Gradation and Leveling: Consider introducing a gradation of difficulty levels for each interactive game. This could accommodate a broader range of skill levels and ensure that the application remains engaging and challenging for users with varying degrees of abilities. By tailoring challenges to individual progress, users can experience consistent improvement over time.

2. Enhanced Avatar Interaction: Elevating the role of the avatar within the application could enhance user engagement. By providing more interactive feedback and guidance, the avatar can become a companion throughout the user's journey, offering

encouragement, tips, and motivation to improve performance.

3. Expanded Gameplay Variety: The creation of additional interactive games tailored to specific skills could enhance the application's educational value. Consider developing games that target more nuanced motor, visual, and memory skills, catering to users who may have specific areas that require attention.

4. Multiplayer Interaction: Exploring opportunities for multiplayer interaction could foster social engagement. Incorporating collaborative or competitive game modes could not only promote skill development but also provide a platform for social interaction and connection among users.

5. Therapeutic and Educational Collaborations: Collaborating with therapists, educators, and experts in the field of ASD could lead to a more comprehensive and integrated application. Customizing content to align with established therapeutic goals and educational curricula could enhance the application's relevance in clinical and educational settings.

6. Longitudinal Impact Studies: Conducting longitudinal studies to assess the long-term impact of the application on skill development, user engagement, and overall quality of life for individuals with ASD is essential. These studies can provide valuable insights into the application's sustained effectiveness over extended periods.

7. Better Information Menus: There could be an improvement on the information menus, where it would be even easier for individuals with autism and/or characteristics of autism understand how to play the games.

As the project continues to evolve, the above strategies present opportunities to harness technology's potential to foster enhanced skill development, engagement, and inclusivity for individuals with ASD. By embracing these future prospects, the interactive application can continue to make meaningful contributions to the lives of its users while remaining at the forefront of technology-driven interventions for autism.

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Appendix A

Information Menus

Figure A.1: Information menu of game 1.

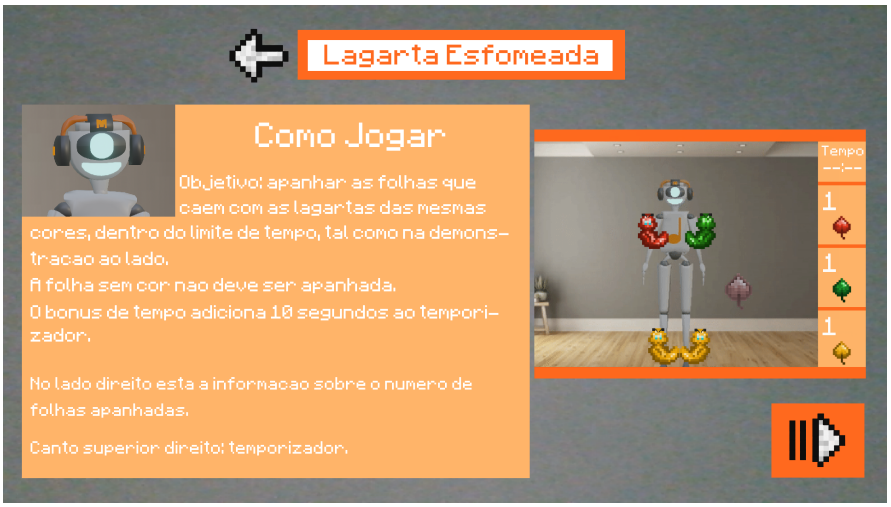


Figure A.2: Information menu of game 2.

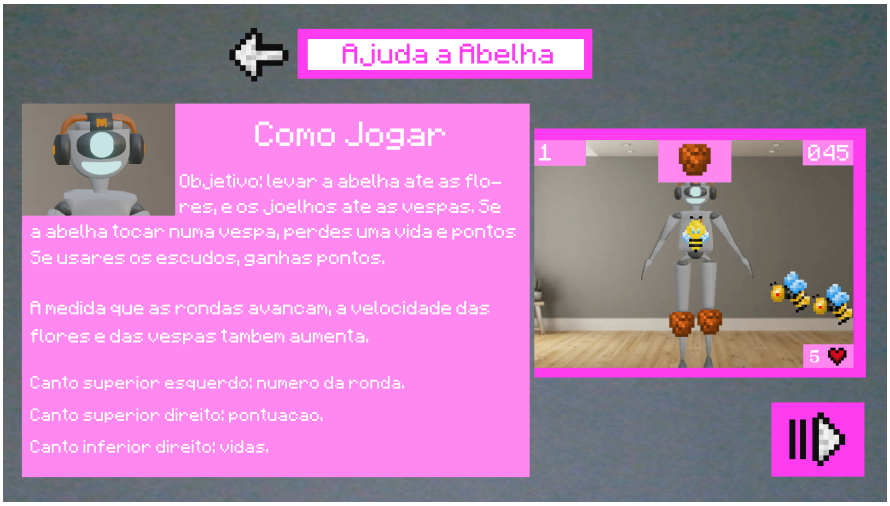


Figure A.3: Information menu of game 3.

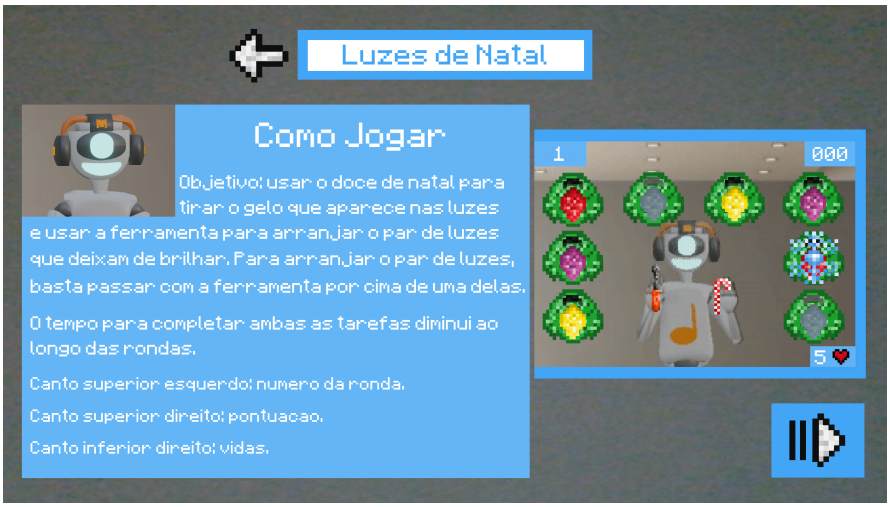


Figure A.4: Information menu of game 4.

Appendix B

Avatar Sequence of Animation

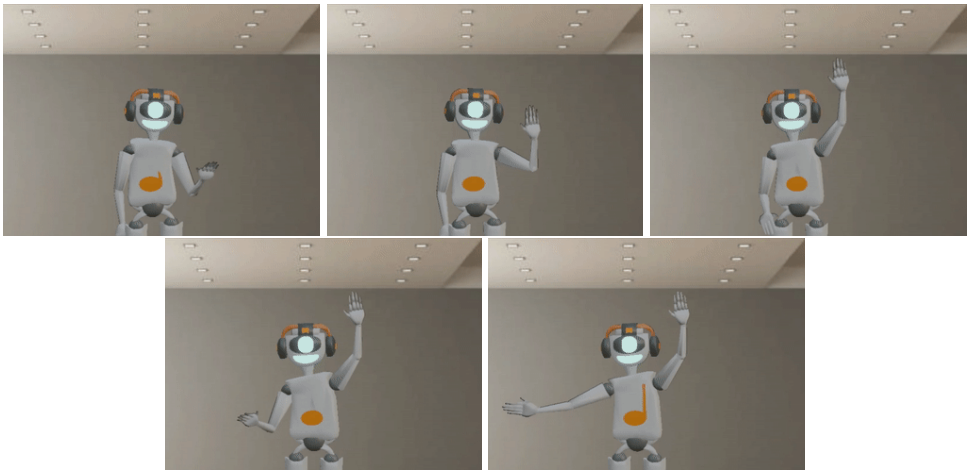
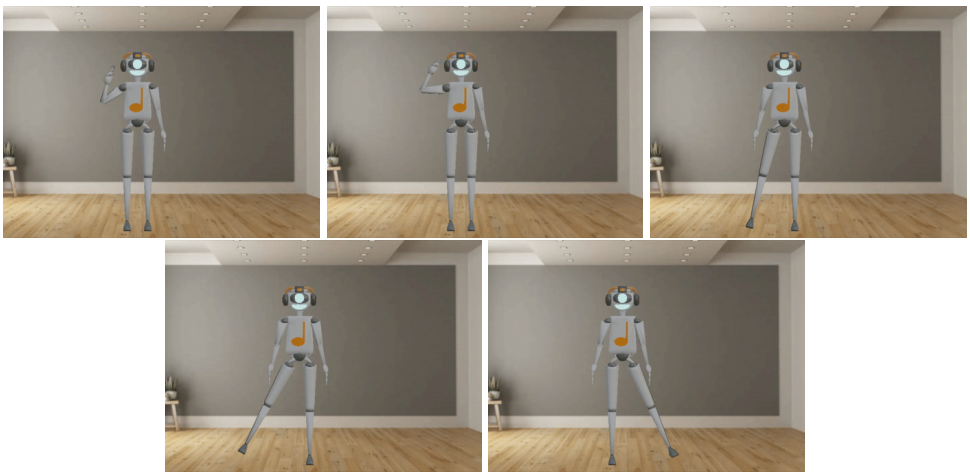


Figure B.1: Avatar animation for the information menu of game 1.



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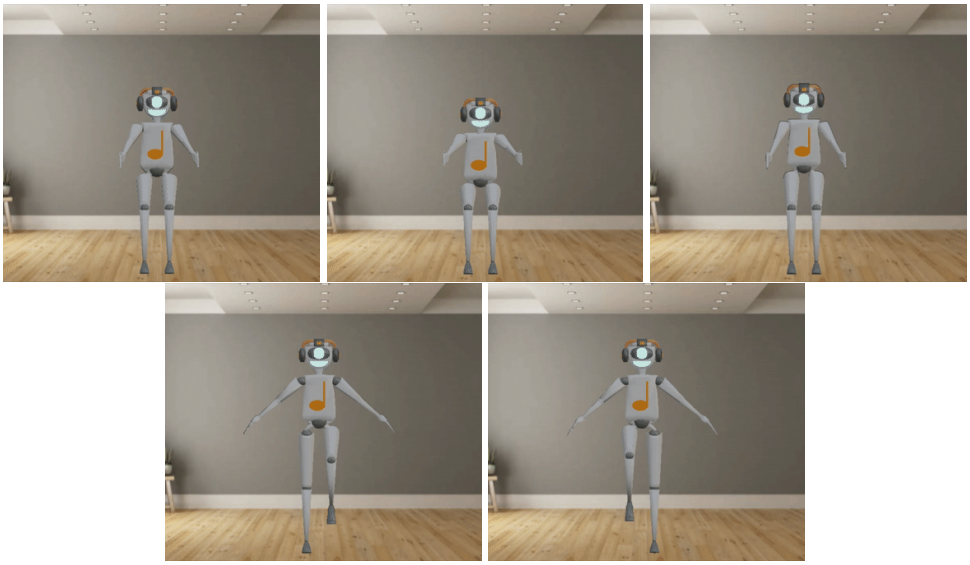

Figure B.3: Avatar animation for the information menu of game 3.

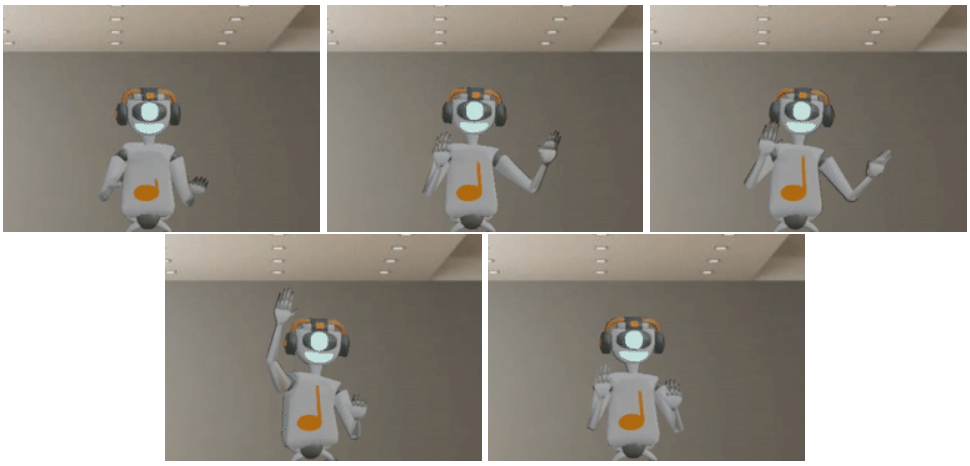

Figure B.4: Avatar animation for the information menu of game 4.

Appendix C

Sprites Sequence of Animation

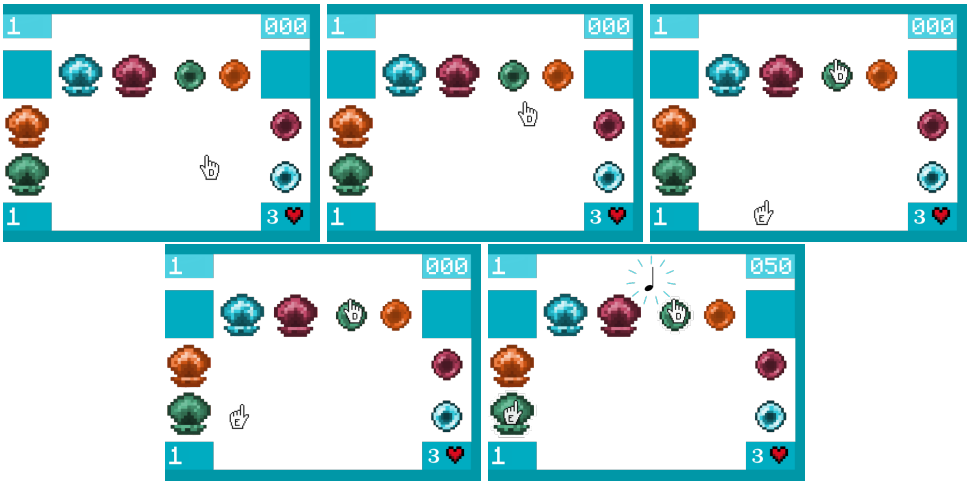

Figure C.1: Sprites animation for the information menu of game 1.

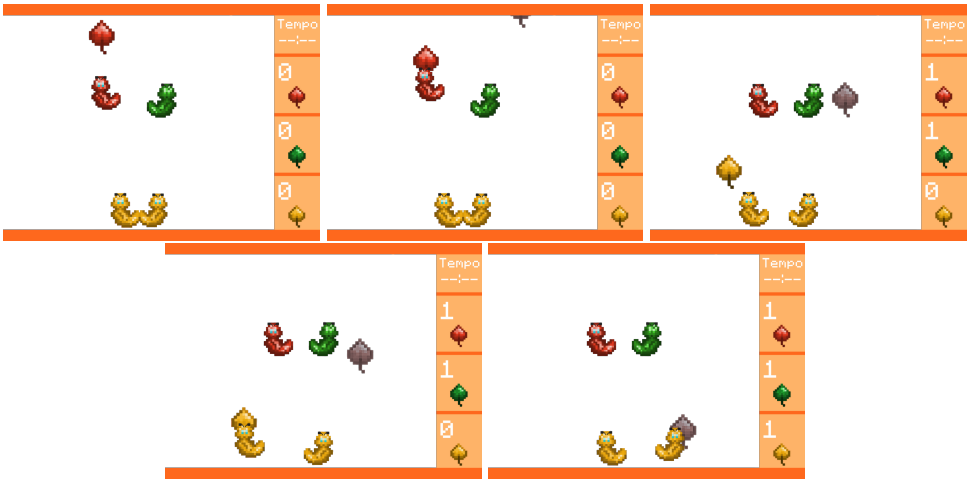

Figure C.2: Sprites animation for the information menu of game 2.

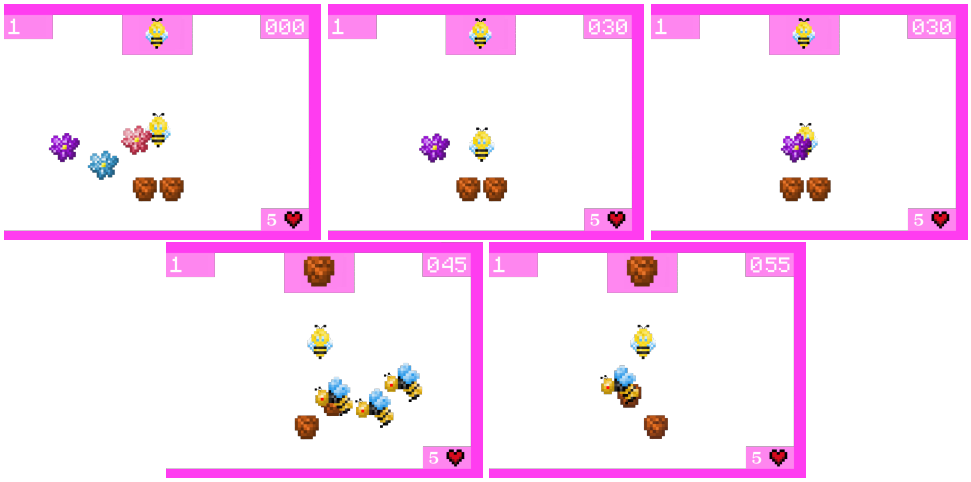

Figure C.3: Sprites animation for the information menu of game 3.

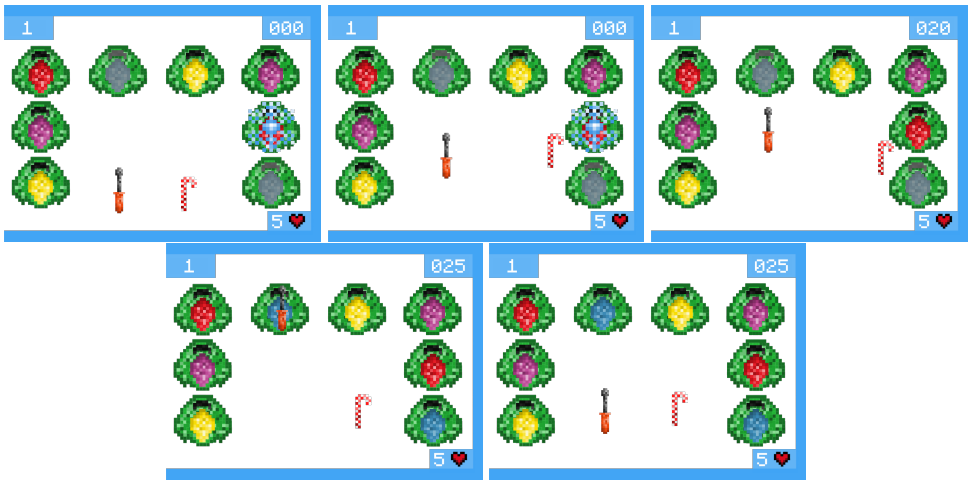

Figure C.4: Sprites animation for the information menu of game 4.

Appendix D

Avatar and Sprites Sequence of Animation

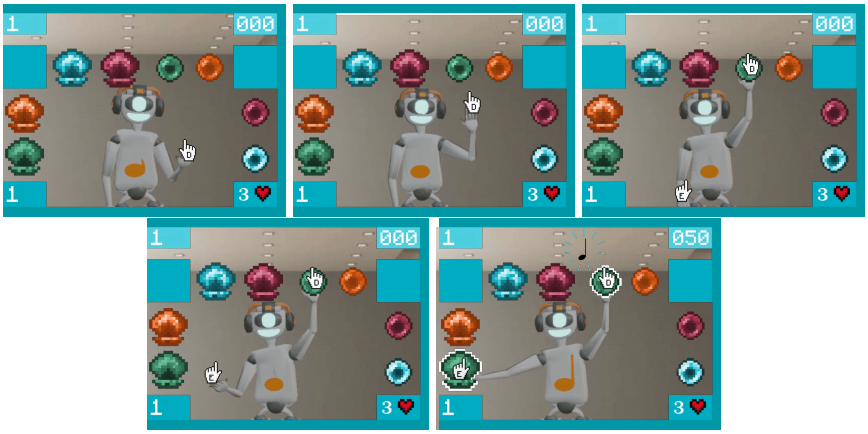

Figure D.1: Avatar and sprites sequence animation for information menu of game 1.

Figure D.2: Avatar and sprites sequence animation for information menu of game 2.

Figure D.3: Avatar and sprites sequence animation for information menu of game 3.

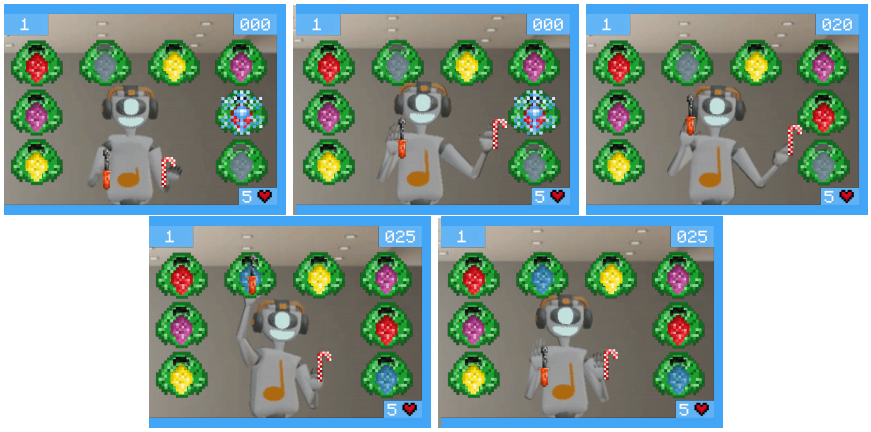

Figure D.4: Avatar and sprites sequence animation for information menu of game 4.

Appendix E

Avatar Voice Lines

Menu	Lines
Information of game 1	"Neste jogo podes jogar sentado ou em pé, sendo que te deves enquadrar no espaço de jogo como achares mais confortável. O objetivo é ver e memorizar a sequência de pares de conchas e pérolas que aparecem no ecrã, e só depois replicar essa mesma sequência usando a mão esquerda para as conchas e a mão direita para as pérolas, selecionando o par ao mesmo tempo. No exemplo ao lado, apareceu o par de concha e pérola verde, então selecionei a concha e a pérola verde ao mesmo tempo. A dificuldade da sequência aumenta com o número de rondas, sendo que na primeira apenas aparece um par, na segunda aparecem dois e assim continua. O jogo termina quando as vidas acabam. Se quiseres ouvir a explicação de novo, passa a mão por cima da minha imagem que se encontra no texto."
Information of game 2	"Neste jogo deves jogar em pé, sendo que te deves enquadrar no espaço de jogo de modo a que te consigas ver dos pés à cabeça no ecrã. O objetivo é apanhar as folhas que caem com as lagartas das mesmas cores, dentro do limite de tempo. Por exemplo, a lagarta vermelha apanha as folhas vermelhas, tal como se pode ver na demonstração ao lado. A folha sem cor não deve ser apanhada por nenhuma das lagartas. Também podes apanhar um bónus de tempo, que adiciona dez segundos ao temporizador. O jogo termina quando o temporizador chegar a zero. Se quiseres ouvir a explicação de novo, passa a mão por cima da minha imagem que se encontra no texto."

Information of game 3	"Neste jogo deves jogar em pé, sendo que te deves enquadrar no espaço de jogo de modo a que te consigas ver pelo menos dos joelhos à cabeça no ecrã. O objetivo é levar a abelha até às flores, e os joelhos até às vespas, tal como está demonstrado ao lado. À medida que as rondas avançam, a velocidade das flores e das vespas também aumenta, sendo que quando a abelha toca na vespa perdes vida. O jogo termina quando as vidas acabam. Se quiseres ouvir a explicação de novo, passa a mão por cima da minha imagem que se encontra no texto."
Information of game 4	"Neste jogo podes jogar sentado ou em pé, sendo que te deves enquadrar no espaço de jogo como achares mais confortável. O objetivo é usar o doce de natal para tirar o gelo que aparece por cima de uma das luzes, e usar a ferramenta para arranjar o par de luzes que se desligou. Para arranjar o par de luzes podes simplesmente passar a ferramenta por cima de uma delas, tal como está demonstrado ao lado com as luzes azuis. O tempo que tens para completar ambas as tarefas fica mais curto ao longo das rondas. O jogo termina quando as vidas acabam. Se quiseres ouvir a explicação de novo, passa a mão por cima da minha imagem que se encontra no texto."
Game mode	"Aqui podes escolher o modo em que queres jogar. Se escolheres o modo de treino, jogas um número limitado de rondas ou de tempo. Se escolheres o modo de jogo, jogas até perderes as vidas ou até o tempo acabar."
Game 1	"Boa!" "Muito bem!" "Isso mesmo!" "Tu consegues!" "Cuidado!"
Game 2	"Muito bem!" "Isso mesmo!" "Tu consegues!"
Game 3	"Boa!" "Muito bem!" "Isso mesmo!" "Tu consegues!" "Cuidado!"
Game 4	"Boa!" "Muito bem!" "Isso mesmo!"
Game over "train" mode	"Muito bem jogado!"
Game over "game" mode	"Muito bem jogado! Se a tua pontuação for melhor do que a última pontuação da tabela do lado direito, podes guardá-la escrevendo o teu nome no retângulo e clicando na tecla Enter."

Table E.1: Table with the voice lines of the avatar on each of the menus.

Appendix F

User Experience Questionnaire

Please make your evaluation now.

For the assessment of the product, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

attractive	○	⊗	○	○	○	○	○	unattractive

This response would mean that you rate the application as more attractive than unattractive.

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular product. Nevertheless, please tick a circle in every line.

It is your personal opinion that counts. Please remember: there is no wrong or right answer!
Please assess the product now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

Figure F.1: User Experience Questionnaire - English.

Por favor dê-nos a sua opinião.

A fim de avaliar o produto, por favor preencha o seguinte questionário. É constituído por pares de opostos relativos às propriedades que o produto possa ter. As graduações entre os opostos são representadas por círculos. Ao marcar um dos círculos, você pode expressar sua opinião sobre um conceito.

Exemplo:

Atraente	○	●	○	○	○	○	○	**Feio**

Esta resposta significa que avalia o produto mais **atraente** do que **feio**.

Marque a sua resposta da forma mais espontânea possível. É importante que não pense demasiado na resposta porque a sua avaliação imediata é que é importante.

Por favor, assinale sempre uma resposta, mesmo que não tenha certezas sobre um par de termos ou que os termos não se enquadrem com o produto.

Não há respostas "certas" ou respostas "erradas". A sua opinião pessoal é que conta!

Por favor, dê-nos a sua avaliação atual do produto em causa.

Por favor, marque apenas um círculo por linha.

	1	2	3	4	5	6	7	
Desagradável	○	○	○	○	○	○	○	Agradável
Incompreensível	○	○	○	○	○	○	○	Compreensível
Criativo	○	○	○	○	○	○	○	Sem criatividade
De Fácil aprendizagem	○	○	○	○	○	○	○	De difícil aprendizagem
Valioso	○	○	○	○	○	○	○	Sem valor
Aborrecido	○	○	○	○	○	○	○	Excitante
Desinteressante	○	○	○	○	○	○	○	Interessante
Imprevisível	○	○	○	○	○	○	○	Previsível
Rápido	○	○	○	○	○	○	○	Lento
Original	○	○	○	○	○	○	○	Convencional
Obstrutivo	○	○	○	○	○	○	○	Condutor
Bom	○	○	○	○	○	○	○	Mau
Complicado	○	○	○	○	○	○	○	Fácil
Desinteressante	○	○	○	○	○	○	○	Atrativo
Comum	○	○	○	○	○	○	○	Vanguardista
Incómodo	○	○	○	○	○	○	○	Cómodo
Seguro	○	○	○	○	○	○	○	Inseguro
Motivante	○	○	○	○	○	○	○	Desmotivante
Atende as expectativas	○	○	○	○	○	○	○	Não atende as expectativas
Ineficiente	○	○	○	○	○	○	○	Eficiente
Evidente	○	○	○	○	○	○	○	Confuso
Impraticável	○	○	○	○	○	○	○	Prático
Organizado	○	○	○	○	○	○	○	Desorganizado
Atraente	○	○	○	○	○	○	○	Feio
Simpático	○	○	○	○	○	○	○	Antipático
Conservador	○	○	○	○	○	○	○	Inovador

Figure F.2: User Experience Questionnaire - Portuguese.

Appendix G

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MuSe4ASD - An Interactive Music Station for Children with ASD

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***Abstract*—This article explores the topic involving children with autism, referencing what this condition is about, as well as the hypotheses for approaching the problem based on the literature reviewed. The proposed approach involves the creation of an adequate space with an immersive interactive system based on musical stimuli, and physical exercise to improve their communication, memory, visual and motor capabilities, and eventually potentiate the development of artistic skills. The development of this interactive system includes the development of an avatar that will be animated using Motion Capture technology, so it can interact with the child and accompany him/her while doing the exercises with fluid movements.**

***Index Terms*—Autism, Music, Physical Activity Promotion, Immersive Systems**

I. Introduction

Autism is a disorder of brain development that affects the act of communication and social interaction, autistic people exhibit frequently stereotyped behaviours and interests that are unusual [1]. There has been an increase in the number of people diagnosed with autism, as it is possible to make the diagnosis earlier. In addition, over the last 20 years, more and more studies have been carried out on this condition, and today we know there are several types of autism. The data represented in the graph in figure 1 encompass the entire spectrum of autism.

Autism manifests itself in the social domain, communication, thinking, and behaviour. It is possible to observe that children with autism have a different interpersonal development than usual, as they tend to isolate themselves or interact in unusual ways, affecting their development and social integration. According to studies, it is estimated that 50% of autistic people do not develop language throughout their lives, which makes communication very difficult [2]. In the domain of thought and conduct, it is worth noting the absence of imagination, memory difficulties, and the tendency to have ritualistic and obsessive behaviours, being that they are dependent on routines. Thus, making an early intervention is essential to start working with the children, as they may have these characteristics mentioned and can improve their condition if they have the right follow-up.

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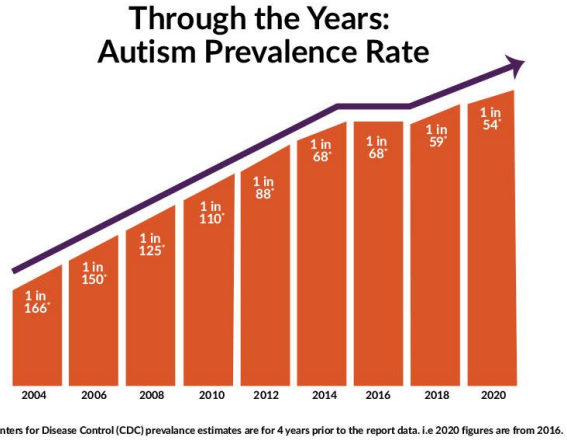

Fig. 1. Autism prevalence rate through the years. We can see there's a large increase in the number of people diagnosed with autism and that it tends to increase more and more.

For this intervention to be even more effective, it is also necessary to create adequate spaces for the child to feel comfortable and thus better potentiate the process of developing their abilities more pleasant. These spaces should comply with factors that may influence the mood and well-being of the child, such as natural light, simplicity of the space, the materials used, proxemics, and acoustics [3].

A. State of the Art

"Music encourages communicative behavior and can encourage interaction with others, which is something that autistic children have great difficulty with" [4]. Music is considered a means of non-verbal expression and turns out to be a type of language that facilitates communication and the expression of feelings [5]. When executing musical activities, a child may be also encouraged to perform controlled and specific movements, which contribute to the organization of thought. When these are performed as group activities, they will contribute to the development of cooperation and communication abilities.

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In addition to music, physical exercises can also be used as a tool for it also has very positive results on the development of the child [6]. Physical activities and exercises are very important for autistic children. Exercises contribute to the release of endorphins, which are hormones that interact with the nervous system functions by relieving pain, reducing stress, and improving the sense of well-being. Furthermore, several studies have shown that exercising regularly improves the motor and social skills of children with autism, also contributing to the reduction of aggressive behaviour and hyperactivity. Physical activities also contribute to the improvement of flexibility, balance, and coordination [7].

Studies have also been carried out on the use of immersive virtual environments as a way to provide controlled therapeutic stimuli for autistic children with a positive contribution to their development, demonstrating that "they were highly motivated by computer technologies, suggesting this could be a powerful educational tool" [8].

There are studies about the impact of memory deficit and autism, reporting that "children with autism exhibit deficits in memory for visual sequences" [9]. Researchers have tried to find a way of helping them work their memory capabilities, using various methods such as verbal information, and visuospatial materials. They reached the conclusion that there were "greater difficulties in ASD for complex stimuli (sentences and stories), compared with simple stimuli (words and pictures)" [10].

B. Objectives

Based on the results of the above-referred studies, this project's goals were defined towards the development of a solution to support the exploration of both music-based activities and physical exercises by autistic children. This solution should be designed so as to be integrated into the children's personal and carefully prepared spaces, e.g. their bedrooms.

This is expected to contribute to the development of their social skills, improve the way they interact with others, enhance communication abilities, improve their memory skills, and use physical exercises to improve balance and coordination.

II. Proposal

Although autistic children tend to avoid contact and interaction with other people, they tend to enjoy and engage with computers and technology, when the interactions occur in safe and trustworthy environments. The proposed concept is centred on making the child move and create music at the same time, that can be used in an adequate space, and supported by a proposedly developed application for a computer or computer-based device.

Given that this application is to be used by the children autonomously, it includes an interactive avatar that provides guidance through the steps of the exercises, explaining what they will do "together".

The demo application is based on the concept of a listen-and-see-and-repeat game, where the child listens to a melody and sees the corresponding figure on the screen, and then explores the designed interaction mechanisms to reproduce the same melody. The interaction mechanism explores a multimodal approach, including state-of-the-art neural networks with reduced computational demands for body tracking, expression recognition, or even gaze tracking. It is also important to give the option to choose the level of melody the child wants to try to hear and repeat, as well as which instrument he/she wants to hear and play. By doing so, we can encourage the improvement of cognitive abilities beyond the repetitive patterns commonly observed in children with autism, while still allowing for a degree of routine to accommodate their interests and avoid potential conflicts.

As the child will move to explore the interaction modalities, he/she attains the second objective which is physical exercise execution, allowing the development of coordination and balance. The accompanying avatar helps with these movements, demonstrating how to do them, and avoiding any possible misunderstanding and consequent frustration feelings.

This proposal differs from other studies done in this type of environment and with the same target audience by using not only visual stimuli, with the avatar and the animations that appear on the screen while they are playing and selecting the mechanisms, but also, at the same time, sounds and music as stimuli for feedback and to offer a relaxing and proper environment for the user to play the games and develop their motor, visual and memory skills. Additionally, the user only needs to interact with the application by using their body at a distance, which gives them more freedom and autonomy than when they have to use material mechanisms, or even depend on others to interact with the system as it was implemented for example in the study of the following reference [11].

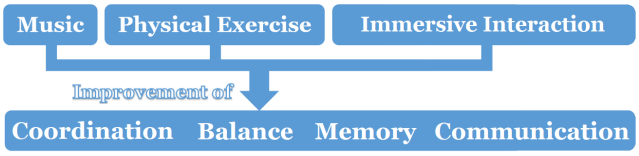

Fig. 2. Objectives scheme.

III. Project Development

The development of this project includes two parts. The first consists on the creation of an avatar (III-A), its animation using motion capture mechanisms(III-B), and the implementation of the interaction mechanism based on the avatar and its animation (III-C). The second part consists of the development of the interactive application (III-D) that integrates the logic of the game with musical and physical exercises, and the interactive avatar.

A. Avatar

The avatar was created using Blender software [12]. The 3D model was entirely designed from scratch, taking into consideration the needs for the subsequent rigging process and association with an armature (skeleton) that will support the animation. Starting with a very simple design of the model's body, and armature has been associated via the establishment

of the weights for each vertex that composes the model mesh. These weights are used to compute the deformations of the model along the animations based on the evolution of the corresponding skeleton (armature) configuration. Figure 3 shows the initial stage of the avatar, and although its humanoid-like realism is not mandatory, its design will be improved, exploring the creation of multiple versions leaving space for choices based on personal preferences.

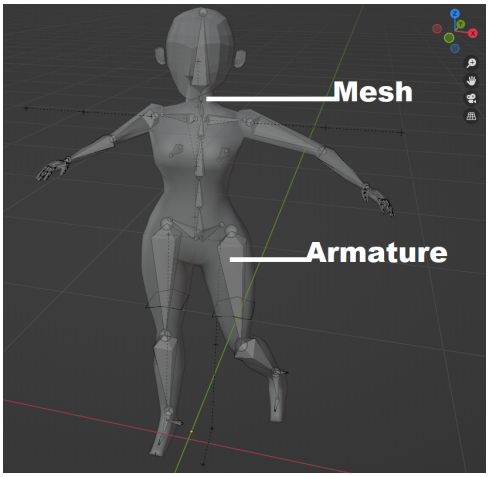

Fig. 3. Avatar base model with the associated armature.

B. Motion Capture

The type of movements the avatar animation is expected to exhibit should be natural, human-like, and fluid. One of the best and simpler methods to attain these requirements in animation is to use human actors to execute the intended movements and register them in a form that can be transferred to humanoid models. This motion capture process (mocap) can be done using a variety of methods and devices, whose characteristics are diverse in terms of cost, real-time usage vs post-processing requirements, and precision.

Fig. 4. Left: Motion Capture Room; Right: One of the cameras with its illumination ring visible.

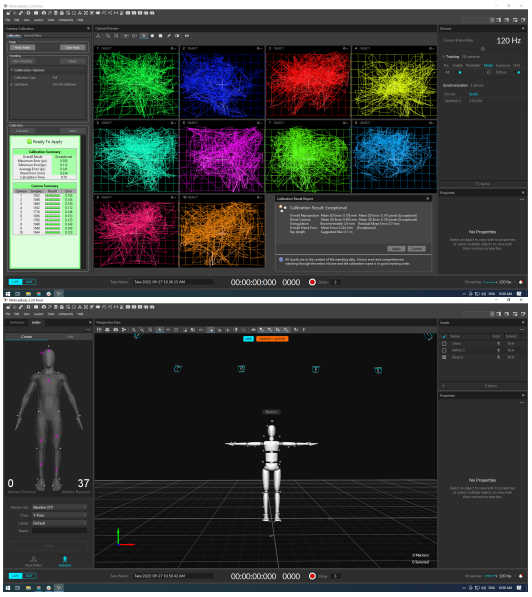

Fig. 5. Top: Setup calibration; Bottom: Pose used to initialize the model at the beginning of each capture sequence.

The mocap system that is available in our laboratory and used in this work was an Optitrack setup, composed of 10 cameras that contain infrared illumination rings, covering an area of $5m \times 5m$, and is able to track multiple reflective markers typically attached to a suit worn by the actor or performer. An optical motion capture software suite named Motive, is responsible for controlling the synchronization of the cameras, doing the inference and providing a user interface supporting both the data acquisition and post-processing. Through these processing steps, this system produces a timed sequence of poses of a skeleton that is later used to animate the model. Furthermore, it has the most accurate measurement system, as it normally generates less than 0.2 mm of measurement error, even when it is used across large tracking areas [13].

C. Retargeting

The acquired motion capture data typically needs to be further processed to produce the intended animation of the virtual character. This stage is called retargeting and is required to adapt data that was acquired for one skeleton model to a possibly different one, in terms of joints or proportions, or other. In this case, the movements are first captured by the cameras and saved in an FBX file format, and then associated with the avatar for its animation.

D. Demo Application

The demo application was developed using Python language and made use of multiple packages such as *MediaPipe* [14] for user hand/body detection and tracking for supporting the interaction, and *python-midi* for musical sounds generation.

The developed demo application provides a mirror-like interaction where the user can see himself/herself on the screen that is invited to interact by performing hand gestures. Besides

some typical menu options such as "Exit" and "Help", the user may enter the game and listen to a random melody one or more times and then choose to try to reproduce it. On success, the user will receive a "well done" message and on failure a "try again" message.

Figure 6 shows some aspects of the application usage.

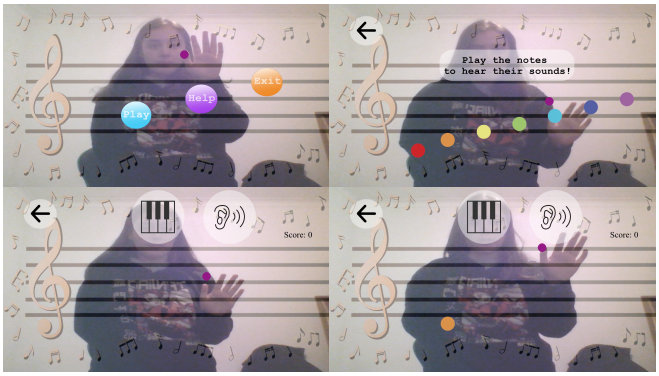

Fig. 6. From top-left to bottom-right: Initial screen menu; Help screen; Play notes screen; and Listen to melody screen.

IV. Preliminary Testing

We had the pleasure of demonstrating the developed application to a group of autistic people, accompanied by their assistants that visited our laboratories. Even knowing that they are not children, mentioning this demonstration is relevant in this section because this group was composed of very diverse subjects within the autistic spectrum, with different cognitive and functional levels.

The interaction took the form of a demonstration of a game, and started with the presentation of the application and its features, explaining how to use it and what was needed to win, as well as showing what happened when someone loses, as it can be seen in figure 7.

Fig. 7. Demonstration on how to interact with the application and play the mini-game.

The group in general showed interest in trying the demo application, and it was a great opportunity to observe the reactions of both more and less functional members (figure 8). The fact that they couldn't make the melody on the first attempt did not impede them to keep trying, as it was clear that they were committed and wanted to "win the game". The less functional members had to have some help when it comes to being able to select the mechanisms available on the screen, as it was not so easy and accessible since they had to coordinate the use of their hands and look at the screen at the same time to see where their hands were and what they were selecting.

Fig. 8. A member of the autistic visitors' group playing the music game.

V. Further Development

Using the demo application developed before as the base, more games will be developed for the final application, some exploring the physical activity exercises for motor and visual coordination, and others more related with visual memory training as well. As there is a spectrum of autism, and many differences in their capabilities such that some may have more difficulties than others, the games will have an option for training and an option to play the game with the objective of getting the highest score in the leaderboard.

The main menu will consist of a title, an information menu about the application, and a space on the left to put the avatar when it is completed (both mesh and associated movements). The player can use the arrows, both left and right, to navigate and choose the game to be played.

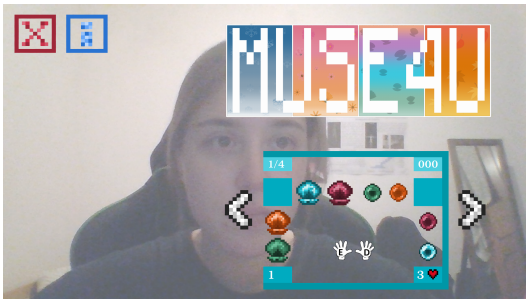

Fig. 9. Main menu of the application.

From there, the player chooses if it wants to train or to play the game.

Fig. 10. Select game mode: training or playing.

For the visual memory training we have the first game, where we need to see a sequence of images and hear the corresponding sequence of sounds, to then repeat that same sequence. Each image of the sequence is showed on the blue squares, the left one for the shells and the right one for the pearls. The player can repeat the image showed in the sequence by using the left hand for the shells and the right hand for the pearls, and touching both shell and pearl at the same time and, as the feedback, hears the sound from that combination. For the training option, there are four rounds, and for the playing option it can be played until all lives are lost.

Fig. 11. First game in training mode.

The second game explores the motor and visual coordination. In this game, we have to work with our feet, hips and elbows, and match each caterpillar with their respective leaf color. As this is a game with a timer, we can also catch a time bonus that will add ten seconds to the timer. For the training option, the timer is set to 1 minute, and for the playing option is set to 5 minutes.

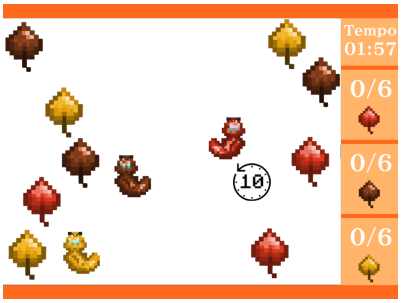

Fig. 12. Second game in training mode.

The third game, which is for the physical activity exercises, and also motor and visual coordination, we work with squats and also by raising the knees. For the squats, we have the bee that we have to guide to get the flowers. But, if there is a wasp, we need to raise our knees to defend the bee. For the training option, there are 8 rounds, and for the playing option it can be played until the wasps win (that happens when they are not defeated at least three times).

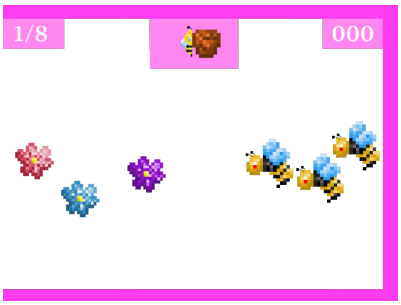

Fig. 13. Third game in training mode.

The fourth game is a reaction game for motor and visual coordination. In this game there are Christmas lights that either need to be fixed (when the light goes out) with the tool (left hand), or they need to be defrosted (when the snow flake appears above one of them) with the sugar cane (right hand). If they are not defrosted in time, the score goes down, and it gets faster from four to four rounds. For the training option, it can be played for six rounds, and for the playing option it can be played until the player fails at least ten times to defrost a Christmas light.

Fig. 14. Fourth game in training mode.

When the game ends, it shows the score obtained, as well as the leaderboard, and, if the player is in the playing mode, it also gives the option of saving their score on the leaderboard by writing their name and pressing "enter".

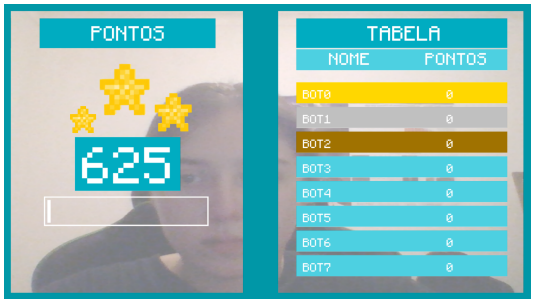

Fig. 15. Menu when the game ends, showing the score obtained and the leaderboard.

Every game as a relaxing background music to create a soft environment, and all the selection mechanisms have a sound for feedback. Also, all the games have a sound feedback when they touch a sprite (depending on what the objective of the game), letting the player know how he/she is doing in the game.

The sprites used were all hand drawn (except the white hands on the first game), by using the software SketchBook and the inspiration from the Minecraft game. This was the chosen design style for the sprites so the application doesn't need to use images from the internet and it allows it to have its own style.

There will be a space on the left of every game screen that will be used to insert the avatar when it is ready.

VI. Conclusion and Future Work

This paper introduced an interactive application centred on music play which is under development and targeting the stimulation of autistic children. By exploring gestures for supporting the interaction enables the possibility of promoting more expressive body movements and thus contributes to physical exercise routines and consequent improvements in motor coordination.

An initial version of this application was demonstrated to a group of autistic people and it was possible to confirm that interactive technology can be quite attractive and stimulating for them, in particular when it is related to music listening and play.

Additionally, the results obtained from the demonstration made to the group mentioned above, from that was possible to observe from a short interaction, and it became clear that some of the implemented mechanisms need to be improved and adapted according to the level of functionality each child may have.

Future works will include the analysis of the gain brought in by the inclusion of the avatar, and to which extent it may replace a human guide. Furthermore, game info menus will also be implemented using the avatar as the demonstrator and also voice recordings to explain how to play the game, because providing the information with visual and audio options is one of the main objectives, as it is important for the user to not have long texts to read. Additionally, the games will be improved in the sense of making them more enjoyable to play, for example with animations when the user interacts with a mechanism, to have more visual stimuli.

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